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Technical Paper 321

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THE EFFECT OF WORKLOAD ON PERFORMANCE OF OPERATORS MONITORING UNATTENDED GROUND SENSORS

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BATTLEFIELD INFORMATION SYSTEMS TECHNICAL AREA

U. S. Army
Research Institute for the Behavioral and Social Sciences

September 1978

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
Technical Paper 321		

4. TITLE (and Subtitle)
THE EFFECT OF WORKLOAD ON PERFORMANCE OF OPERATORS MONITORING UNATTENDED GROUND SENSORS

5. TYPE OF REPORT & PERIOD COVERED
FINAL REPORT
Jan 74 - Feb 75

6. PERFORMING ORG. REPORT NUMBER
--

7. AUTHOR(s)
Lawrence R. Edwards, Sterling S. Pilette, Billy E. Biggs
HRB-Singer, Inc.; and Harold Martinek, ARI

8. CONTRACT OR GRANT NUMBER(s)
DAHC19-74-C-0030

9. PERFORMING ORGANIZATION NAME AND ADDRESS
HRB-Singer, Inc.
P.O. Box 60
Science Park, State College, PA 16801

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
2Q762717A721

11. CONTROLLING OFFICE NAME AND ADDRESS
U.S. Army Research Institute for the Behavioral and Social Sciences
5001 Eisenhower Avenue, Alexandria, VA 22333

12. REPORT DATE
September 1978

13. NUMBER OF PAGES
68

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
--

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
--

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

12 73 p. 18 ARI 19 TP-321

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

--

18. SUPPLEMENTARY NOTES

--

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Unattended ground sensors	Target acquisition
Seismic sensors	Belt
Grid	Workload effects
Surveillance	Multiple displays

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Requirement: THE OBJECTIVE WAS To determine the effect of workload (target activity level and number of sensors used) on unattended ground sensor (UGS) operators' target-detection ability, false-alarm rate, and direction and speed estimation accuracy.

Procedure: Experienced operators monitored activations of UGS used in grids under six workload conditions--two levels of target activity x three levels

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

78 11 22 028

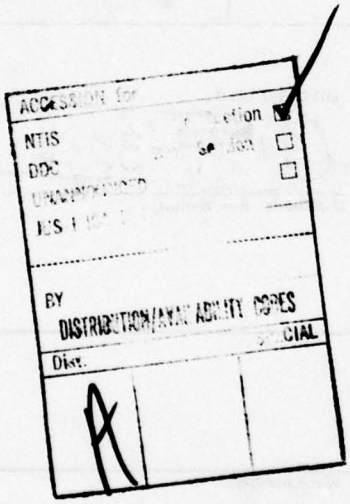
20.

of number of sensors monitored. Target activity level was defined as either 5 or 14 vehicle groups per 27 sensors per hour. The operators monitored in counterbalanced sequence 27 sensors (3 grids), 54 sensors (6 grids), and 108 sensors (12 grids).

Results: Percentage of detections decreased linearly from 85% (4 to 6 vehicle groups per hour presented on 27 sensors) to 26% (about 40 vehicle groups per hour presented on 108 sensors). Without special training, operators should monitor no more than 60 sensors being activated by a maximum of 10 vehicular groups per hour (detection completeness for this condition was 76%). The number of false alarms and the accuracy of speed estimation did not significantly change over workload. Operator accuracy in direction estimation decreased significantly as a function of workload from true azimuth ±30° to true azimuth ±54°.

degrees

degrees



Technical Paper 321

THE EFFECT OF WORKLOAD ON PERFORMANCE OF OPERATORS MONITORING UNATTENDED GROUND SENSORS

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5001 Eisenhower Avenue, Alexandria, Virginia 22333

Office, Deputy Chief of Staff for Personnel
Department of the Army

September 1978

Army Project Number
2Q762717A721

Intelligence Systems

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FOREWORD

The Battlefield Information Systems Technical Area is concerned with the demands of the future battlefield for increased man-machine complexity to acquire, transmit, process, disseminate, and use information. The research focuses on the interface problems and interactions within command and control centers and is concerned with topographic products and procedures, tactical symbology, information management, user-oriented systems, staff operations and procedures, and sensor systems integration and use.

One area of special interest is human factors problems of presentation and interpretation of surveillance and target acquisition information. One relatively new source of intelligence information is remote monitoring of the battlefield using seismic, acoustic, and magnetic unattended ground sensors. When these remote sensors are activated by enemy personnel or vehicle movement, a monitor display located behind our lines indicates the activity. The operator can determine from this display not only the presence of the enemy but also information such as the direction and speed of convoys and personnel, the number of vehicles in a convoy, and the composition of the convoy (e.g., armored versus wheeled vehicles).

This publication investigates the effects of workload on operator performance as defined by target activity level and number of sensors monitored. These results have implications for the design of monitor displays and operator-assignment doctrine.

Research by the Army Research Institute for the Behavioral and Social Sciences (ARI) in the area of sensor systems integration and use is conducted as an in-house effort augmented by contracts with selected organizations--in this case, HRB-Singer under contract DAHC19-7A-C-0030. The effort is in response to requirements of Army Project 2Q762717A721 and to special requirements of the U.S. Army Intelligence Center and School, Fort Huachuca, Ariz., Headquarters, MASSTER, Fort Hood, Tex., and the Remotely Monitored Battlefield Sensor System Project (REMBASS). Special requirements are contained in Human Resource Needs 74-21 and 74-73.

The cooperation of participating personnel of the unattended ground sensor platoon of the 502d Military Intelligence Battalion, 2d Armored Division, Fort Hood, Tex., is appreciated. Special thanks are given to LTC Dunlap, 2d Armored Division G2 Officer, CPT Jones, UGS platoon commanding officer, and SGT Stollings, UGS Platoon NCO.

JOSEPH ZEIDNER
Technical Director

THE EFFECT OF WORKLOAD ON PERFORMANCE OF OPERATORS MONITORING UNATTENDED GROUND SENSORS

BRIEF

Requirement:

To investigate the effect of workload on operator performance as defined by target activity level and number of unattended ground sensors (UGS) used.

To determine operators' target-detection ability, false-alarm rate, and direction and speed estimation accuracy to help establish system capability.

Procedure:

Following an orientation and training session, experienced UGS operators monitored, in sequence, each of three event recorder displays showing activations of UGS used in grids. The operators monitored 27 sensors (3 grids) on one display, 54 sensors (6 grids) on the second, and 108 sensors (12 grids) on the third. Each grid was composed of nine minisids, spaced 500 m apart to form a 1,000 m^2 field. Operators encountered periods of high and low target activity that were of equal time duration. Operators reported each target they detected and estimated speed and direction of movement.

Findings:

The number of sensors monitored and the target activity level significantly affects UGS operator performance. The operators' ability to detect targets decreased as either activity level or number of sensors increased. Operators' ability to estimate target direction also decreased as activity level increased. Although target speed was underestimated, no significant differences were found between any of the experimental conditions for this variable. The false-alarm rate was low (one per 3 hours).

Utilization of Findings:

Careful judgment should be exercised in assigning workloads to UGS operators. Operators without special training or experience should not monitor more than 60 sensors, and then only if target activity is low. If operators are required to monitor more than 60 sensors or if target activity is high, intelligence estimates of target activity based on UGS operator reports should be adjusted upward.

The grid deployment of UGS is a valid method for surveillance of large areas to detect vehicular movement. Operators' target-detection performance was good even though they had received no training or experience in monitoring UGS employed in grids. The false-alarm rate (one per 3 hours) and the 85% detection rate for the 27-sensor, low-target-activity condition demonstrates the initial capability of the use of UGS employed in a grid. Although the true speed of vehicles passing through the grid was underestimated for all conditions, the "cross-country" speed estimate (used for predicting time of arrival) is as accurate as that made for sensors deployed in the more typical string configuration along roads or trails.

Special training should be instituted for target detection under high-workload conditions and for the estimation of the target's direction of travel. Direction estimation was poor ($\pm 40^{\circ}$ on the average); but in view of the atypical target paths used in this research, the above value should not be generalized to the usual operational situation.

THE EFFECT OF WORKLOAD ON PERFORMANCE OF OPERATORS MONITORING UNATTENDED GROUND SENSORS

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THE EFFECT OF WORKLOAD ON PERFORMANCE OF OPERATORS MONITORING UNATTENDED GROUND SENSORS

INTRODUCTION

Unattended ground sensors (UGS) represent part of the Army's capability for detection, location, and target acquisition of enemy activity at a remote location. UGS can be used alone or in combination with ground surveillance radar, night vision devices, aerial surveillance (radar, infrared, photographic, and visual), signal intelligence, patrols, and observation and listening posts to produce timely and reliable intelligence information. Several types of UGS that the Army uses can be categorized according to the method of remote sensing: seismic, acoustic, magnetic, electromagnetic, and infrared. UGS are tactically used in offensive and defensive operations by units from small independent patrols to full division operations. Uses of UGS in offensive operations include the following:

- Target acquisition--sensors' real-time detection capability leads to immediate reaction.
- Landing (drop) zone--sensors monitor enemy activity for future airmobile assault.
- Combat sweep--sensors monitor enemy withdrawal or attack activity.
- Ambush--sensors establish enemy habits and are employed with a remote firing device and command-detonated mines.

Uses in defensive operations include the following:

- Base camp defense--sensors provide warning of enemy presence and extend listening post/observation post detection range.
- Convoy security--sensors provide ambush detection and warning.
- Border surveillance--sensors provide warning of enemy presence and fire control information for real-time reaction.
- Beach defense--sensors provide warning of counterattack in beachhead situations.

UGS can be employed in three ways: string, grid, and alerting. In string employment, UGS are used along a potential transportation route (land or water). Whether hand-emplaced or air-delivered, the objective is to implant sensors accurately so that their location with respect to the route and their separation distances are known. This

information enhances the manual readout function by permitting relatively accurate direction, speed, and length of column information to be derived from the sensor activation patterns. If hand-emplaced, the sensor locations can be pinpointed on a map and "seated" properly in the ground. Various combinations and mixes of sensor types have been field-tested by the Army.

In grid employment (sometimes called field, belt, gate, or gate array), UGS are deployed in a regularly spaced, two-dimensional pattern to "cover" a given geographical area or field (Figure 1). The grid would normally be used in defensive operations for surveillance and target acquisition of the forward edge of the battlefield and behind enemy lines and for guarding areas of importance in the rear. Whether hand-emplaced or air-delivered, the objective is to implant the sensors accurately so that their locations are known and ground distances between the sensors are about equal. Again, hand emplacement is best for knowing sensor location and for proper "seating." The grid is designed to maximize the probability of detecting and acquiring enemy forces intruding in any portion or from any direction within a large area (1 to several km^2). Because the path of the target is estimated, the operator can make only gross estimates of speed. Until special operator training procedures and job aids are developed, the accuracy of estimates of speed, direction, and number of targets will be below that usually obtained with string employment of UGS.

In alerting employment, UGS are used to "cover" a given route or ground area, but for various reasons their exact locations and the ground distances between them are not accurately known. This situation can occur when sensors are delivered by mortar or artillery in areas that are inaccessible to friendly units or when sensors have been air-delivered under poor visibility conditions. Whatever the cause, the operator knows only the approximate location of the sensors. Reliable detection of activity can be made, but additional information such as speed, number of targets, and direction cannot be computed accurately.

The U.S. Army Intelligence Center and School (USAICS) teaches the string employment concept and the alerting employment concept. Other than a brief overview, however, the school does not train students in monitoring and interpretation procedures for grid employment. Thus, in the past, UGS operators were not likely to encounter grid-monitoring situations. Because of the shift in emphasis from the Southeast Asia type of conflict, however, the possibilities of grid applications in area-intrusion situations have increased. The grid employment can be used in almost all the offensive and defensive situations discussed previously.

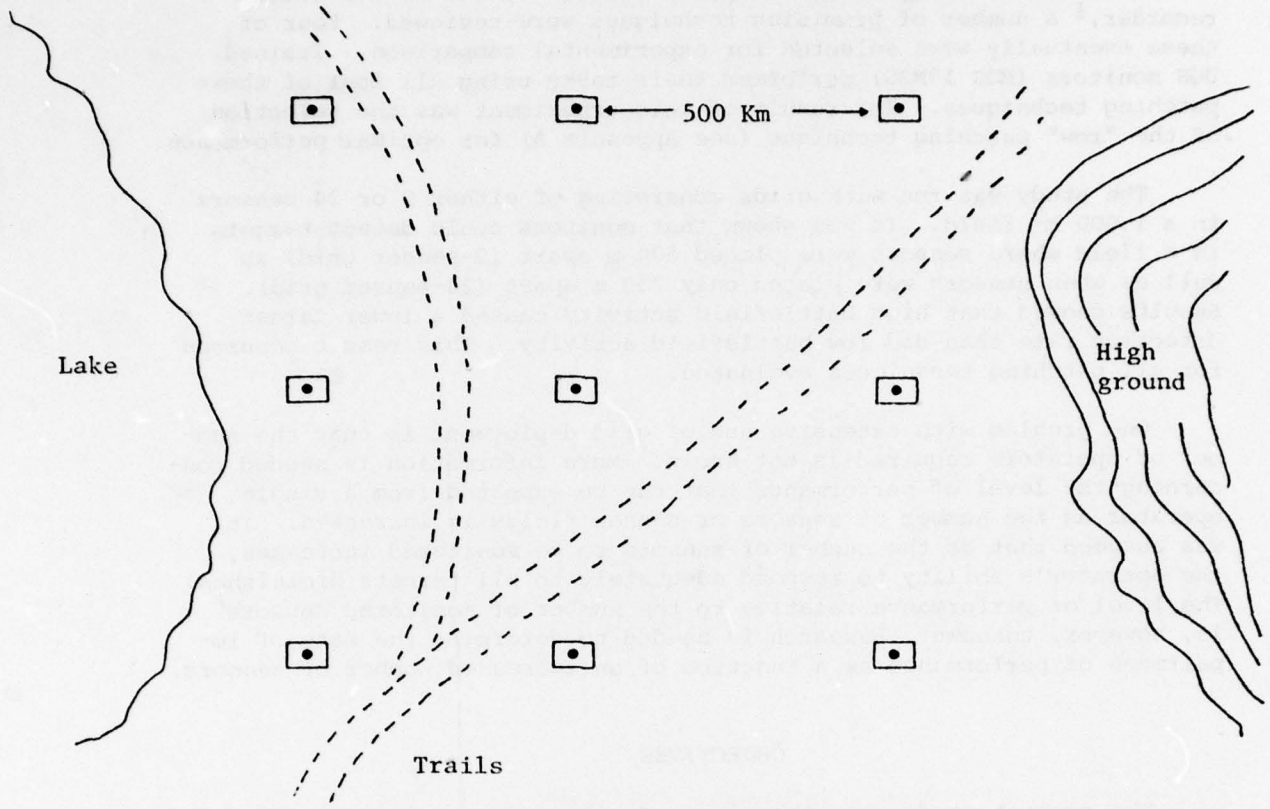

Figure 1. Example of a 9-sensor grid used at a natural chokepoint.

In a recent study of how to patch sensors to the RO 376 event recorder,[1] a number of promising techniques were reviewed. Four of these eventually were selected for experimental comparison. Trained UGS monitors (MOS 17M20) performed their tasks using all four of these patching techniques. The result of this experiment was the selection of the "row" patching technique (see Appendix A) for optimal performance.

The study was run with grids consisting of either 9 or 24 sensors in a 1,000 m^2 field. It was shown that monitors could detect targets in a field where sensors were placed 500 m apart (9-sensor grid) as well as when sensors were placed only 250 m apart (24-sensor grid). Results showed that high battlefield activity caused a lower target detection rate than did low battlefield activity. This result occurred for all patching techniques evaluated.

One problem with extensive use of grid deployment is that the number of operators required is not known. More information is needed concerning the level of performance that can be expected from a single operator as the number of sensors or sensor fields is increased. It was assumed that as the number of sensors to be monitored increases, the operator's ability to respond adequately to all targets diminishes. The level of performance relative to the number of monitored sensors is, however, unknown. Research is needed to determine the rate of impairment of performance as a function of an increased number of sensors.

OBJECTIVES

The present study was, therefore, designed (a) to investigate the effect of workload on operator performance as defined by target activity level and number of unattended ground sensors used and (b) to determine operators' target-detection ability, false-alarm rate, and accuracy of direction and speed estimation to help establish system capability.

METHOD

Population and Sample

The population of concern consisted of Army enlisted UGS operators (MOS 17M20) who had been trained at the USAIC&S and who had received some field experience with an operational unit. The sample consisted of 28 enlisted personnel of the 163d Military Intelligence Battalion stationed at Fort Hood, Tex., who served as operators. Each operator had participated in one or two of the following exercises: Fort Huachuca

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[1] Pilette, S., Biggs, B., Edwards, L., & Martinek, H. Optimum Patching Technique for Seismic Sensors Employed in a Grid. ARI Technical Paper 320, August 1978.

exercises, August 1972; Gallant Hand, Fort Hood, April 1973; Brave Shield, Fort Bliss, November 1973; Operational Readiness Training Test, Fort Hood, February 1974; Advanced Individual Training (AIT), Fort Huachuca, February 1974.

Independent Variables

Displays. Each operator monitored in succession three displays, each presenting activations from a different number of sensors--27, 54, and 108. Order of presentation of the displays (or number of sensors) to the subjects was counterbalanced to prevent practice or learning from confounding this variable.

Scenario--Order of Presentation. Each operator was presented 14 30-minute scenarios (RO 376 event recorder plots portraying sensor activations) in one of 14 counterbalanced orders. Scenarios and order are confounded but not with displays.

Target Activity. A target was defined as one or more vehicles in a group. The low-target-activity level was set at two to three targets per 27 pens per 30 minutes. The high-activity level was set at six to eight targets per 27 pens per 30 minutes. The targets (sensor activations) in the low- and high-target-activity levels were different. Thus, this variable is confounded with scenario (target difficulty).

Dependent Variables

The dependent variables in the study--correct detections, false alarms, direction, and speed--were scored as follows:

False Alarms. If an operator reported a target in the scenario when no target was causing activations of the designated pens, or if an operator reported two or more targets on the same pens when there was only one target, the response was classified as a false alarm.

Detection and Percent Detection. If an operator reported a target in the scenario at the time a target was causing activations on the designated pens, the response was classified a correct detection. Percent detection is the number of detections divided by the number of targets available for detection.

Direction. The direction of a target path was scored from the point where a target left the grid. An 18-point sector scale was used, with each sector being 10^{o}. The response was scored as a correct direction if the target path that the subject drew was anywhere in the correct sector. If the target path was drawn in a sector other than the true sector, a deviation score was given corresponding to the number of sectors removed from the correct sector.

Results on target direction should be generalized with caution. Because of space restraints in the area assigned for the collection of sensor activation data at Fort Bragg, after passing through the grid most targets were required to turn and travel parallel to the last row and approximately 100 m from it. Thus, most of the targets activated the last row of sensors, making the direction estimates more difficult than if the target had kept going straight as expected.

Speed. Deviation scores were used in scoring speed. If an operator reported the correct speed of a target, he was given a score of zero. If the response was incorrect, the deviation in meters per minute from the correct value was determined.

Research Design

The research design is presented in Table 1. The evaluation was a comparison of monitor performance on three displays (27, 54, and 108 sensors). The independent variables analyzed were target activity (2), scenario-order (14), and displays (3). The design counterbalanced the sequence of scenario presentations, sequence of displays, and sequence of high and low target activity. All operators were presented with all 14 scenarios and each of the three displays. The effects of the three primary independent variables and their interactions were analyzed using the analysis of variance and Duncan's Multiple Range test.[2]

Apparatus

Twelve RO 376 tactical recorder simulators were used. The simulator consists of a viewing window and a drive mechanism that presents sensor activations at the same rate of speed and in the same format as the actual 30-channel RO 376. To display 54 sensors, the same simulator was used but with a larger window, similar to the Bass III recorder. Two of these were used for displaying 108 sensors. Previously prepared RO 376 plots were displayed on the simulators.

Scenario Construction

Realistic scenarios were constructed from activations recorded during Army field exercises conducted at Fort Bragg. These exercises consisted of a vehicle or groups of vehicles moving through a 1,000 m^2 field at known rates of speed along specified routes. Because the activations were recorded on audio tape, selected parts could be "played back" to an RO 376 event recorder in any order required to construct a

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[2] Burning, J. L., & Kimtz, B. L. Computational Handbook of Statistics. Glenview, Ill.: Scott, Foresman and Company, 1968, pp. 115-117.

Table 1

Research Design (30-Minute Periods)

Order	Subject	Scenarios					
		T_1	T_2	T_3	T_4	T_5	T_6
1	1 2	1[a]	8	2-3[b]	9-10	4-5-6-7[c]	11-12-13-14
2	3 4	11-12-13-14	4-5-6-7	8	1	9-10	2-3
3	5 6	3-4-5-6	10-11-12-13	7	14	1-2	8-9
4	7 8	8-9	1-2	10-11-12-13	3-4-5-6	7	14
5	9 10	7-1	11-8	2-3-4-5	9-10-11-12	6	13
6	11 12	13	6	14-8	7-1	9-10-11-12	2-3-4-5
7	13 14	5	12	1-2-3-4	8-9-10-11	6-7	13-14
8	15 16	13-14	6-7	12	5	8-9-10-11	1-2-3-4
9	17 18	5-6	12-13	4	11	7-1-2-3	14-8-9-10
10	19 20	14-8-9-10	7-1-2-3	12-13	5-6	11	4
11	21 22	6-7-1-2	13-14-8-9	4-5	11-12	3	10
12	23 24	10	3	13-14-8-9	6-7-1-2	11-12	4-5
13	25 26	3-4	10-11	5-6-7-1	12-13-14-8	2	9
14	27 28	9	2	10-11	3-4	12-13-14-8	5-6-7-1

[a] A 30-minute period containing 1 scenario was displayed on 27 pens.

[b] A 30-minute period containing 2 scenarios was displayed on 54 pens.

[c] A 30-minute period containing 4 scenarios was displayed on 108 pens.

scenario on RO 376 plot paper. Scenarios had been constructed from the field data on two previous studies (Pilette et al., 1975), and these scenarios served as the primary source of data for this study.

An analysis of monitor performance (see Appendix B) on 113 of the targets presented during the previous study[3] was accomplished to determine the level of difficulty (p values) for each of the targets. A broad range of target difficulty was used in the scenarios to provide realistic target situations for the monitor. No changes were made to the original target activation patterns; however, some of the target activations were displayed a second time in a manner that represented a perfectly symmetrical reversal of the actual sensor grid. This reversal did not affect the temporal sequence of activations or the quantity of activations. The purpose of the reversal was to provide a greater variety of target paths for the monitor to observe. This manipulation doubled the number of target paths available. Appendix C shows the results of such a reversal on a target pattern.

This study required a total of 14 30-minute scenarios. A scenario was presented on RO 376 plot paper, which was subdivided into three 9-pen groupings, with each grouping representing a 9-sensor grid. Pens 1 to 9 represented Grid 1, pens 11 to 19 represented Grid 2, pens 21 to 29 represented Grid 3, and pens 10, 20, and 30 were idle.

Seven of the scenarios contained two to three targets and constituted the low activity condition. The other seven scenarios contained six to eight targets and constituted high activity. The entire 7 hours of scenarios contained a total of 64 targets, with 15 targets in low activity and 49 targets in high activity. A target-quality distribution chart for the targets presented in this study is included in Appendix D. This chart shows that the predicted detection completeness of the low-target-activity targets is 68% whereas that for the high-target-activity targets is 57%. Thus, the target difficulty of the two groups of targets is different, and the results should be interpreted accordingly.

Test Procedure

The training and test schedule is presented in Table 2. During the first day, officers associated with the UGS platoon were briefed, classrooms were prepared, and drive mechanisms were readied and placed into position. Each operator then participated in the following three sessions in the order given:

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[3] Edwards, L., Rockford, D., & Shvern, U. Comparison of Four Displays for Use in an Unattended Ground Sensor Grid Deployment Situation. ARI Technical Paper 281, April 1977.

Table 2

Schedule of Administration Onsite at Fort Hood

		Room A		Room B
Day 1	AM	Unit briefings Classroom set-up		
	PM	Equipment set-up, Subject Scheduling		
Day 2	AM	Group I (14 subjects) Orientation Briefing Grid Briefing Test Procedure Training	8:00-11:00	
	PM	Group I (14 subjects) Patch Technique (Row) Training	1:30-4:00	Group II (14 subjects) Orientation Briefing Grid Briefing Test Procedure Training
Day 3	AM	Group II (14 subjects) Patch Technique (Row) Training	8:00-11:00	
	PM	Group A (9 subjects) Multi-display Training Data Collection	2:30-5:00	
Day 4	AM	Group B (8 subjects) Multi-display Training Data Collection	8:00-12:30	
	PM	Group C (8 subjects) Multi-display Training Data Collection	12:30-5:00	
Day 5	AM	Group D (3 subjects)	8:00-12:30	
	PM	All operators Critique and Review	1:30-3:00	

Session I	Orientation Briefing (see Appendix E) Introduction to the Grid (see Appendix F) Test Procedure Training (see Appendix G)
Session II	The Grid Deployment Using Row Patching (see Appendix A)
Session III	Multidisplay Training (see Appendix H)

All familiarization and training activities were intended to prepare operators for the data collection after Session III. The orientation briefing of Session I gave operators an idea of the purpose of the study and what was going to happen. Operators were then introduced to UGS grid deployment and were shown examples of target intrusion. The test procedure training was intended to teach operators the necessary procedures, including the use of the three target logs (Appendix I).

In Session II, operators were trained in target detection and direction and speed estimation using the row-patching technique for UGS displayed in a 9-sensor grid. As with the test procedure training, a self-administered workbook (Appendix A) was used with instructor guidance. This training was an introduction to the row-patching technique with a 9-sensor grid, not a comprehensive grid training program.

The multidisplay training in Session III used a round-robin approach. Each operator monitored each display condition for approximately 10 minutes, during which time he would report any targets and provide the required responses. The same approach was also used during data collection. Each operator monitored each display condition for 1 hour and then switched to a different condition as required by the experimental design.

RESULTS AND DISCUSSION

Percent Detections

The analysis of variance results for percent detections are given in Table 3. A statistically significant effect at the .001 level was found for percent detections for the Display (number of sensors) variable. A Duncan Multiple Range Test (Burning & Kimtz, 1968) was subsequently performed comparing detection performance for the three displays. Table 4 shows that all three displays were significantly different from each other at the .05 level. Thus, as workload increased (from 27 pens to 108 pens), operator performance decreased.

Table 3 shows that the difference between the high and low activity levels is significant at the .001 level. This significant result indicates that a large number of targets entering a sensor grid over a short period of time interferes with the monitor's ability to detect targets

Table 3

Analysis of Variance for Percent Detections

Source of variation		df	Sum of squares	Mean square	F	Significance level
Between subjects		27	17550.90			
O	(scenario-order combination)	13	14350.57	1103.80	4.83	.005
S	(subjects w. groups) [error (a)]	14	3200.33	288.60		
Within subjects		140	132147.00			
D	(displays)	2	21830.79	10915.40	37.31	.001
DO	(scenario-order combination x displays)	26	13985.54	537.91	1.84	NS
DS	(displays x subjects w. groups) [error (b)]	28	8191.67	292.56		
A	(activity level)	1	47000.59	47000.59	91.64	.001
AO	(scenario-order combination x activity level)	13	10081.41	775.49	1.51	NS
AS	(activity level x subjects w. groups) [error (c)]	14	7180.33	512.88		
AD	(displays x activity)	2	381.59	190.80	1.21	NS
ADO	(scenario-order combination x display x activity)	26	18750.41	721.17	4.26	.001
ADS	(display x activity x subjects w. groups) [error (bc)]	28	4744.67	169.45		
Total		167	149697.90			

individually. Again, as workload increased (low to high activity), performance decreased.

Table 4

Duncan Multiple Range Test on Percent Detections by Display

	108 pen	54 pen	27 pen	Shortest significant range
Means	43	57	71	
43		14.64*	27.86*	9.334
57			13.33*	9.804

*Significant at the .05 level.

Table 5 shows the mean percent detection rates for all displays and activity levels. The percentage of targets detected is greatest for the 27-pen display, low-target-activity condition, and smallest for the 108-pen display, high-target-activity condition.

Table 5

Mean Percent Detections for Display by Activity

Target activity	Display condition			
	27 pen	54 pen	108 pen	Average
Low	85	76	60	74
High	56	39	26	40
Average	71	58	43	57

The percent detection rate during high target activity on the 27-pen condition was approximately the same as that during low target activity on the 108-pen condition. This finding is noteworthy because these two conditions are the only ones that present approximately the

same number of targets within the same time period--approximately one every 4 minutes. These results are shown in Figure 2, which indicates the percent detections as a function of the number of targets presented. The slight displacement of the line could be attributed to chance variations, individual target difficulty differences between the high- and low-target-activity condition, or the increase in difficulty associated with target overlap and crowding on the display. The latter problem was observed in scoring the operator reports and is hypothesized as one error source that may be reduced through special training. As noted earlier, there was a difference in target difficulty between high and low target activity based on figures from previous research (Appendix D). These differences (predicted percent detection for low = 68%, for high = 57%), if applicable, would account for the displacement of the curves and result in the dotted line in Figure 2.

Table 6 shows the total detections for all displays and activity levels. These figures indicate that the number of detections increases as the number of sensors or target activity increases, even though the percentage of targets detected decreases (Table 5). These results were expected because of the greater number of actual targets presented as the number of sensors or target activity increased. The average number of targets presented to an operator for each display/target activity condition is given in Table 7.

Table 6

Average Number of Detections for Display by Activity
(30-minute periods)

Target activity	Display condition		
	27 pen	54 pen	108 pen
Low	1.8	3.3	5.1
High	3.9	5.4	7.2

Table 3 also shows statistically significant effects for scenario-order combinations. Because the Scenario-Order variable was confounded with subjects, individual differences are believed to be responsible for much of the variation. To what extent the order of presentation of the 14 scenarios affected monitor performance cannot be precisely determined. The three-variable (activity-display-order) interaction effect is significant; however, this statistical result cannot be clearly interpreted in view of the confounded nature of the Scenario-Order variable.

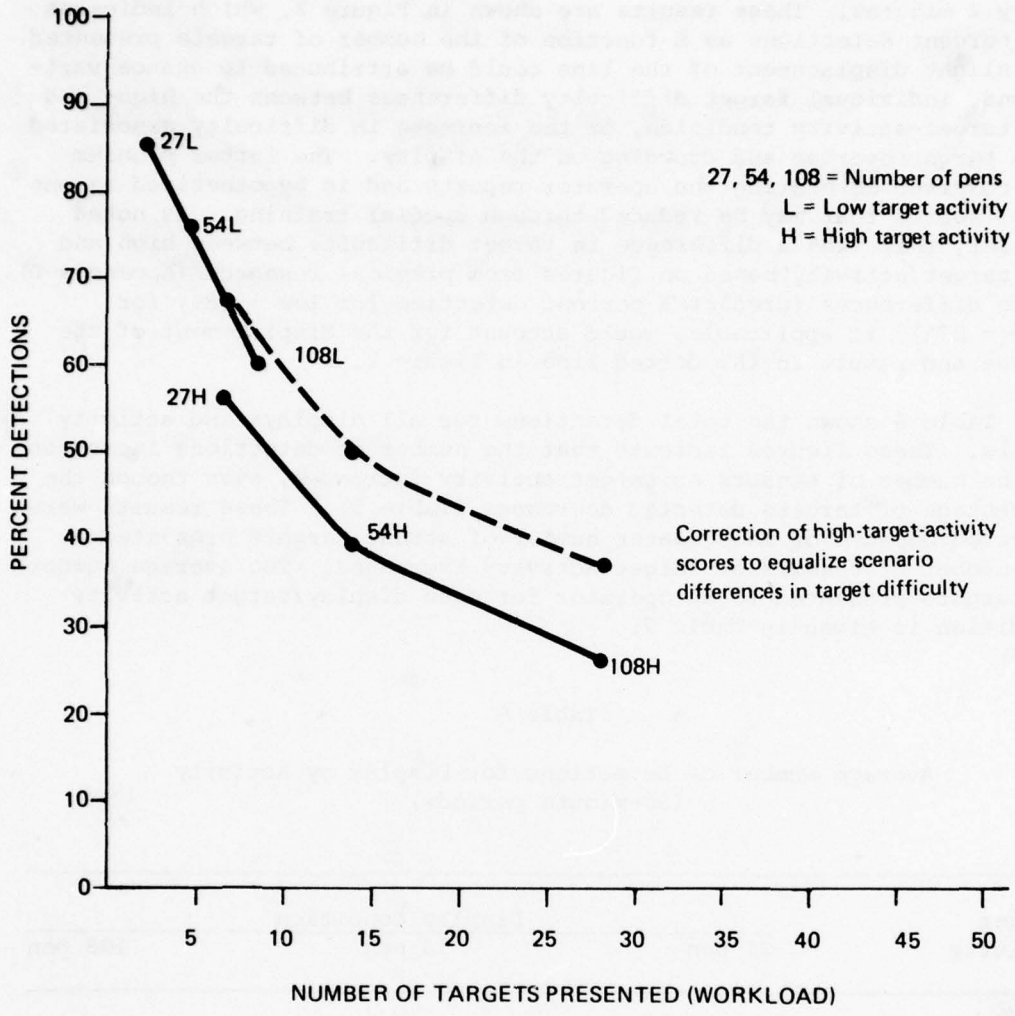


Figure 2. Effect of workload on percent detections.

Table 7

Number of Targets Presented for Display/Activity Condition

Target activity	Display condition		
	27 pen	54 pen	108 pen
Low	2.1	4.3	8.6
High	7	14	28.2

False Alarms

A frequency polygon of the false-alarm data shows a marked positively skewed distribution and was judged to not approximate the normal curve. Because of the skewed distribution and paucity of false alarms, a statistical evaluation was not conducted.

The average number of false alarms for each display and target activity condition is shown in Table 8. Mean false-alarm rates are similar for all three displays and for both target activity levels. False-alarm rates this low were considered to be relatively useless for research purposes but highly important for operational implications. On the average, only one false alarm was reported by each operator for 3 hours of monitoring.

Table 8

Average Number of False Alarms for Each Display/Activity Condition

Target activity	Display condition			
	27 pen	54 pen	108 pen	Average
Low	.14	.18	.29	.20
High	.25	.18	.00	.14
Average	.20	.18	.15	.18

Speed

Mean speed deviation scores are shown in Table 9. Scores for each activity level and display are negative and the overall mean is negative. A two-tailed t test for a single mean indicates that a 54 m per minute deviation is significantly different from zero at the .01 level; therefore, when sensors are used in a grid, operators underestimate the true speed of targets.

Table 9

Mean Speed Deviation for Display by Activity in Meters per Minute

Target activity	Display condition			
	27 pen	54 pen	108 pen	Average
High	-47	-67	-54	-56
Low	-47	-60	-48	-51
Average	-47	-63	-51	-54

The probable explanation for this underestimation of speed is the operator's assumption that targets were traveling in a straight line. Thus, if a target activates a sensor 5 minutes after activating a previous one located 1,000 m away, the monitors would estimate the target's speed to be 200 m per minute. If, however, the target had traveled on an indirect route (as would be the case in cross-country travel) between the two sensors and covered a distance of 1,100 m, its actual speed would have been 240 m per minute. If actual target speed is necessary for some purpose, such as target classification, operator underestimates of the speed can be a problem in grid deployment of sensors. If the primary purpose of determining target speeds, however, is to aid in predicting target arrival time at a certain point or line, then these underestimates are the correct values for this application providing the terrain characteristics remain relatively constant.

Table 10 shows no significant effects of the primary variables on speed deviation. Underestimation of speed was consistent across displays, activity levels, and scenario-order combinations.

Direction

The analysis of variance results for direction deviation scores are given in Table 11. The only statistically significant effect found was for the target activity variable. The average direction deviation for the low-target-activity condition was 3.44 (or $\pm 34.4^{o}$), whereas that for the high-target-activity condition was 4.4 (or $\pm 46.4^{o}$).

Table 10

Analysis of Variance for Speed Deviations

Source of variation	df	Sum of squares	Mean square	F	Significance level
Between subjects	27	279682.83			
O (scenario-order combination)	13	68671.16	5282.59	.35	NS
S (subjects w. groups) [error (a)]	14	211011.67	15072.26		
Within subjects	140	436354.67			
D (displays)	2	8343.42	4171.71	.94	NS
DO (scenario-order combination x displays)	26	100760.92	3875.42	.87	NS
DS (displays x subjects w. groups) [error (b)]	28	124136.33	4433.44		
A (activity)	1	737.52	737.52	.17	NS
AO (scenario-order combination x activity)	13	31081.15	2390.85	.55	NS
AS (activity) x subjects w. groups [error (c)]	14	60087.33	4291.95		
AD (displays x activity)	2	311.48	155.74	.07	NS
ADO (scenario-order combination x display x activity)	26	52744.85	2028.64	.97	NS
ADS (display x activity x subjects w. group) [error (bc)]	28	58151.67	2076.84		
Total	167	716037.50			

Table 11

Analysis of Variance for Direction Deviations

Source of variation	df	Sum of squares	Mean square	F	Significance level
Between subjects	27	292.78			
O (scenario-order combination)	13	162.90	12.53	1.35	NS
S (subjects w. groups) [error (a)]	14	129.88	9.28		NS
Within subjects	140	669.62			
D (displays)	2	13.91	6.96	1.69	NS
DO (scenario-order combination x displays)	26	188.14	7.24	1.76	NS
DS (displays x subjects w. groups) [error (b)]	28	115.21	4.11		NS
A (activity)	1	60.84	60.84	15.72	01
AO (scenario-order combination x activity)	13	50.21	3.86	1.00	NS
AS (activity) x subjects w. groups [error (c)]	14	54.16	3.87		NS
AD (displays x activity)	2	17.23	8.62	2.77	NS
ADO (scenario-order combination x displays x activity)	26	82.89	3.19	1.03	NS
ADS (display x activity x subjects w. group) [error (bc)]	28	87.03	3.11		NS
Total		962.40			

Results in Figure 3 indicate that it is more difficult for operators to determine a target's direction of travel when other targets are in or around the same area. It may be that operators have difficulty distinguishing sensor activations caused by one target from activations caused by other targets, or that time pressures affect operator accuracy. Figure 3 shows the effect of workload on direction deviation score. There appears to be a consistent relationship for the high-target-activity condition between direction deviation and number of targets, although no significant effects were found in the analysis of variance for the display variable or its interaction with target activity. No consistent effect appears for the low-target-activity condition.

The mean direction deviation score for all activity levels was $\pm 40.4^{\circ}$ from ground truth. Although scores were somewhat better when target activity was low, this amount of deviation might be considered high for a field commander's purposes. Operators are more familiar with sensor-string data in which the target's direction is generally a known road or path. The grid employment situation causes more difficulty in determining direction. A need for more training and experience with grid use seems to be indicated. These results, however, should be generalized with caution to the operational situation in view of the atypical target paths required after the targets had passed through the grid.

CONCLUSIONS AND RECOMMENDATIONS

The result of increasing operator workload (number of targets an operator must detect and report) is a decrease in the percentage of detections. This effect occurred if workload was increased by increasing the number of pens (or sensors) to be monitored from 27 to 54 or from 54 to 108 with the density of targets per pen held constant. The effect also occurred if workload was increased by increasing the target density per pen (target activity) with the number of pens held constant.

We can conclude that increasing either the number of sensors an operator must monitor or the level of target activity will cause a decrease in the percentage of detected targets; furthermore, a combined increase in both number of sensors and activity level will cause a greater impairment. The extreme comparison of operators monitoring 27 pens under low target activity versus operators monitoring 108 pens under high target activity revealed a decrease in percent detection from 85% to 25%.

It is critical that field officers be aware of these effects. They must decide which levels of target detection are acceptable and which are not, and then make provisions for adequate UGS operator support. Intelligence analysts should note the effects of increased

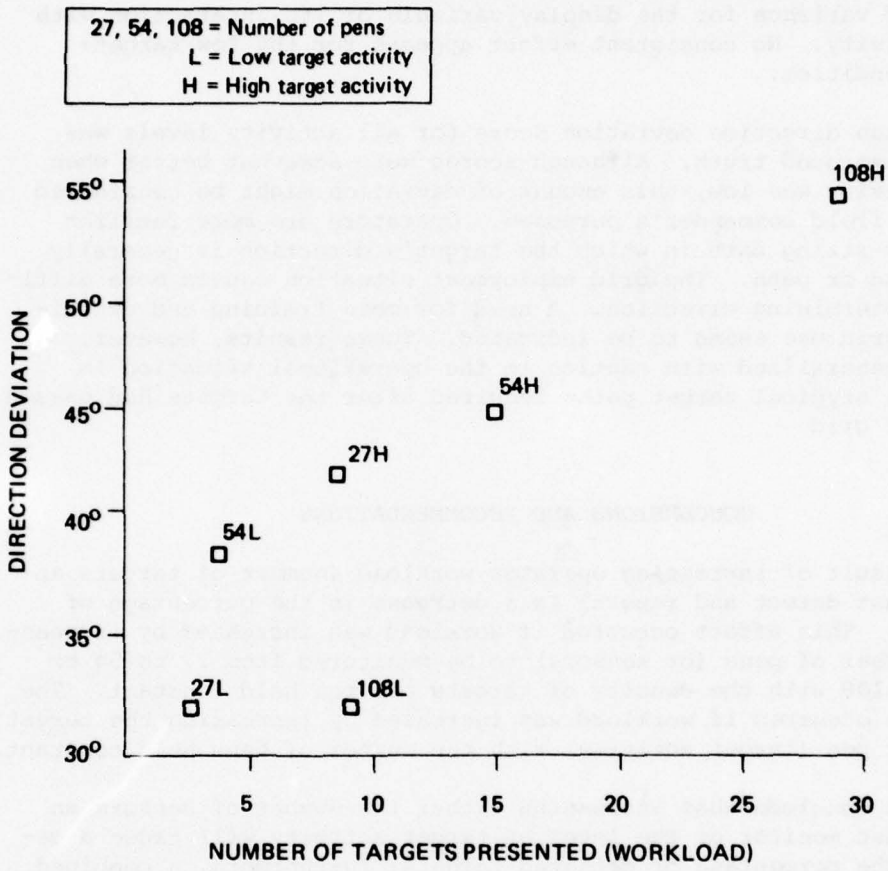


Figure 3. Effect of workload on direction estimation accuracy.

numbers of sensors and activity level when interpreting operator reports and should make corresponding adjustments to their intelligence estimates.

If workload was increased by increasing target activity level, a decrease was found in the accuracy of target-direction estimates made by the operator. Moreover, results on operators' target-direction estimates indicate that these estimates are of little use operationally because of the large average deviation from the true target direction. It is not concluded, however, that they should be eliminated from the operator reports at this time. Two temporary causes for these poor estimates can be hypothesized--operator ability and unusual activation data. If operator ability is the problem, an error analysis and training program should be researched. If the results are due to the atypical target paths used after passing through the grid, these results should not be generalized to operational situations. Additional activation data should be collected in a field exercise more suitable to obtaining generalized estimates of the operator's capability to provide valid target-direction estimates.

In the present experiment, errors of omission (missed detections) were far more frequent than errors of commission (false alarms). Only 29 false alarms were generated by the 28 operators, each working for a 3-hour period. Efforts to improve systems capability should concentrate on errors of omission, while insuring that the false-alarm rate does not increase.

Target speeds were significantly underestimated for all displays and both activity levels. There were no significant differences in the degree of underestimation between any of the display conditions or target activity levels. The underestimates of target speed can be more useful information than actual speed. The underestimates occur because the operator must assume a relatively straight target path between two points on the grid used for making a speed estimate. In fact, a target will make slight (5^{o} to 30^{o}) changes in direction to avoid obstacles and, thus, will travel a greater distance than the operator estimates. Therefore, the operator will underestimate the actual speed. Given that indirect routes were available for the targets, the underestimates are not surprising. Whenever a grid deployment of sensors is used, an underestimate of target speed can be expected unless the terrain is relatively free of obstacles. However, because the field officers will typically be interested in determining when a target will reach a certain area, the target's actual speed is immaterial. The estimated cross-country speed, which is an underestimate of the actual target speed, will be the appropriate measure for this purpose. Some adjustment in the estimated speed values may be required if there is a significant difference in terrain between the area the target has traversed and the area it is approaching. Similarly, if actual target speed is needed for target identification purposes, the operators' estimates must be increased appropriately.

As a result of this research, it is recommended that

1. Operator performance, as represented by percentage of target detections, false-alarm rate, and speed estimations, is sufficient for operational use given a low workload (30 to 60 sensors and low target activity).

2. Special training on the interpretation of unattended ground sensors used in a grid should be developed, especially for the higher workload situations and for estimating target direction.

3. Doctrine should be developed defining the use of operators in the field consistent with Army requirements for target detection, availability of operators, and workload/performance tradeoffs.

APPENDIX A

THE GRID DEPLOYMENT OF SEISMIC SENSORS USED FOR PATCHING

Objective

To familiarize you with how the row patching technique is used with a grid deployment pattern and to train you on how to use it to detect and report on targets using the seven-step procedure. Part I of this workbook deals with training and Part II deals with practice in target reporting.

PART I - TRAINING

What is the Row Patching Technique?

The row patching technique is defined as patching the sensors which have been deployed in a symmetrical grid pattern into horizontal rows on the X-T plot. Look at the next page of this workbook. The top half of Figure A presents a symmetrical 9-sensor grid which shows the sensors grouped into three horizontal rows: Row I, Row II, and Row III. All the sensors are seismic and are set at the same medium gain setting. The bottom half of Figure A contains the seven-step reporting procedure that you are already familiar with. Notice that the sensor numbers are shown. At this time pull Figure A out of this booklet, write your name in the upper right-hand corner and place it on your desk where it is clearly visible.

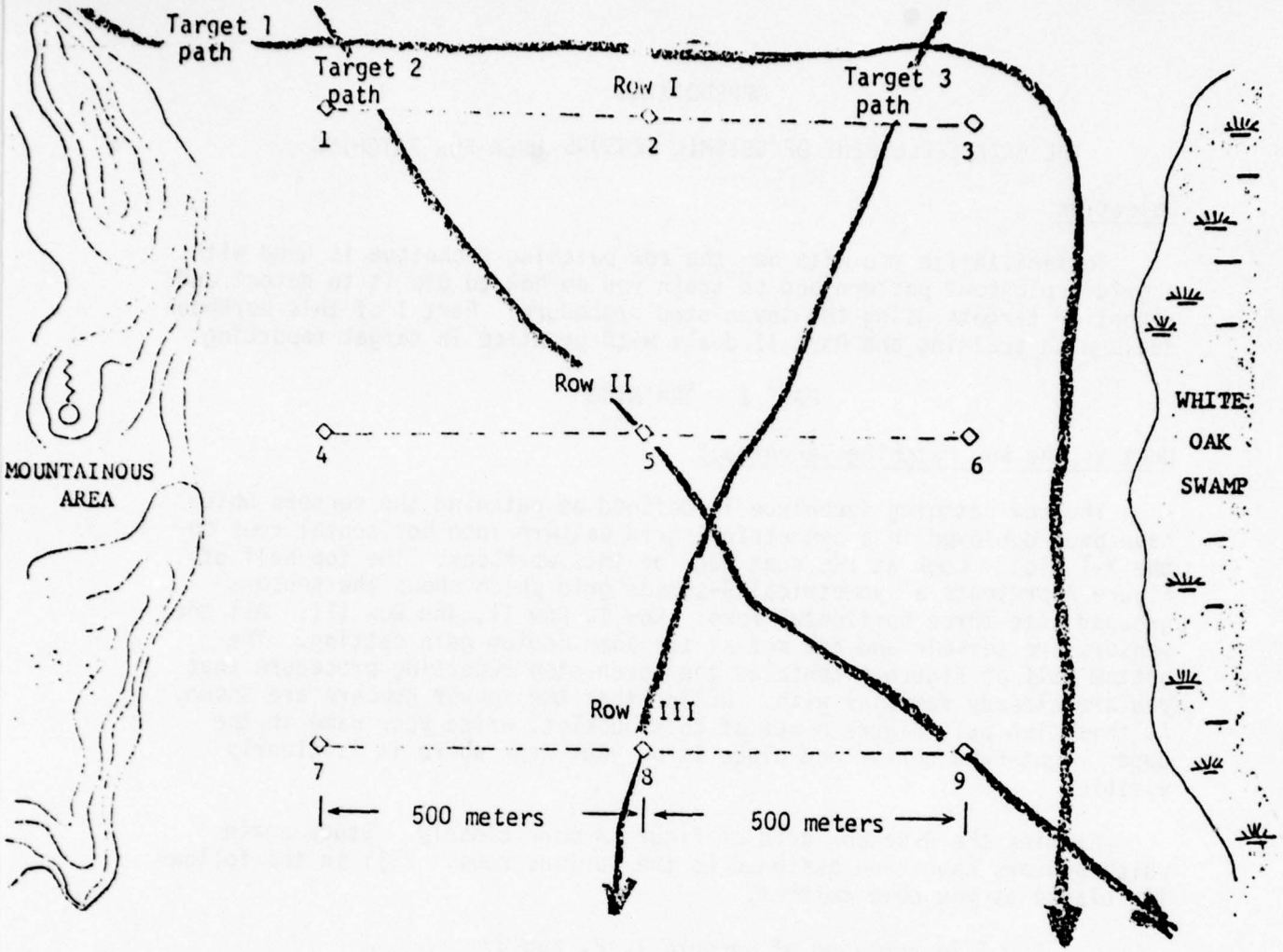
Examine the 9-sensor grid of Figure A more closely. Study again which sensors have been assigned to the various rows. Fill in the following blanks as you come to them.

Row I is composed of sensors 1, 2, and 3.
Row II is composed of sensors 4, ___, and 6.
Row III is composed of sensors ___, ___, and ___.

How do you Detect Targets?

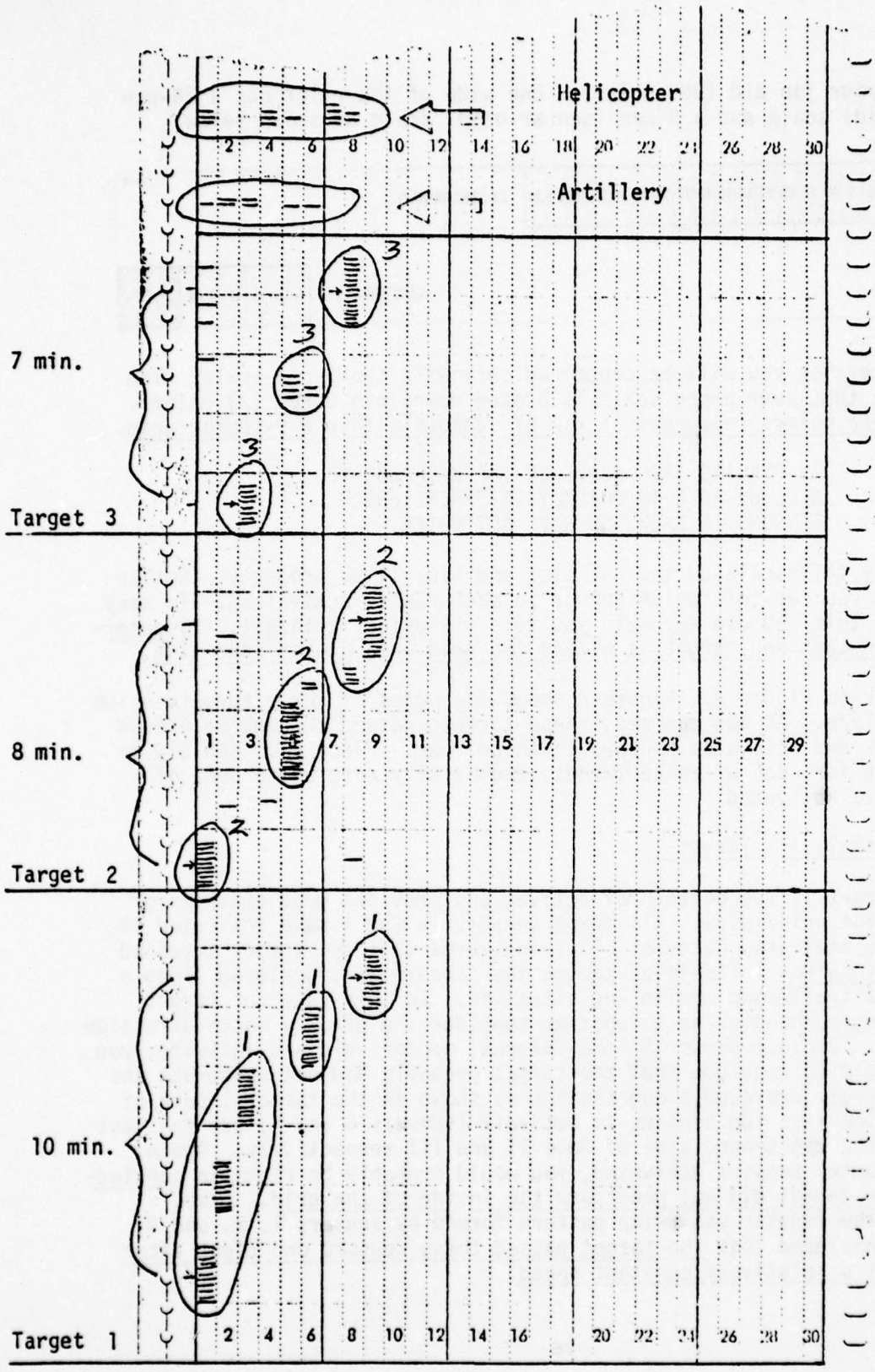
Any target that enters this grid will have to pass through and around one or more of these rows. What this means to you is that you will be able to detect and report on targets by observing what activation activity is taking place in each row. In other words, any target entering or leaving the grid area will have to activate one or more sensors in one or more rows.

Now look at the X-T plot in Figure B. The sensors that you have just studied in the grid are each patched to a pen of the same number on this X-T plot (one-for-one). Pen 1 on the X-T plot, therefore, refers to sensor 1 on the grid, etc. Throughout this lesson the terms "sensor" and "pen" will be used interchangeably.



STEP 1 TARGET NUMBER	STEP 2 ESTIMATED DISTANCE (METERS)	STEP 3 CONFIDENCE LOW->HIGH 25,50/50, 75,100	STEP 4 FIRST AND LAST SENSORS ACTIVATED	STEP 5 MID-POINT TIME (min) DIFFERENCE	STEP 6 ESTIMATED SPEED	STEP 7 TARGET TYPE
1	2100	100%	1,9	10	2100/10= 210	
2	1450	100%	1,9	8	1450/8= 181	
3	1050	100%	3,8	7	1050/7= 150	

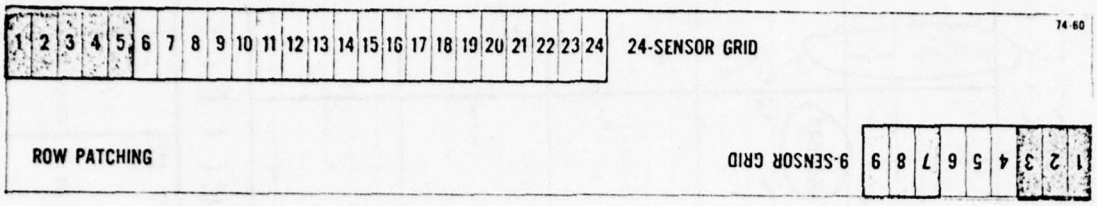
Figure A. Target log.



Sensor		
Row	Pen	ID
I	1	1
	2	2
	3	3
II	4	4
	5	5
	6	6
III	7	7
	8	8
	9	9

Figure B. X-T plot for row patching using 9-sensor grid (learning targets).

Find your job aid (UGS Ruler). One side of the ruler has a 24-pen (sensor grid) scale and a 9-pen (sensor grid) scale as shown below.



For this exercise you will be concerned only with the 9-pen scale. You will notice that your p-pen scale is broken down into three (3) colors. Each of these colors represents a row of sensors within a 9-sensor grid.

BY PLACING THIS SCALE ON THE X-T PLOT YOU WILL BE ABLE TO QUICKLY DETERMINE WHICH SENSORS IN EACH ROW HAVE ACTIVATED.

Now lay this scale on the X-T plot and line it up properly. Notice how quickly you can tell which sensor in each row is activating. In many situations, this job aid may help you to: (1) detect a target, (2) determine if more than one target is within the grid area at the same time.

Go back to Figure A. Figure A shows the paths of three targets which we will analyze. As you can see, these targets passed through or around various rows and activated sensors in these rows. Place your job aid on the X-T plot for each of these targets and briefly note which pens of each row have activated.

a. Example 1 - Target 1

For target 1, the pattern of activations provides good examples of interpretation principles. All three sensors in Row I have activated in a noticeable stairstep pattern. This indicates that the target traveled somewhere along Row I itself as though the sensors were deployed along a road as in a trail/road monitoring situation. In this case the target was traveling perpendicular to what we consider the primary watch direction of the grid. Because sensor 5 (the internal sensor) did not activate, you should be able to conclude that the target probably did not penetrate the grid, but merely traveled along the top as shown in the target 1 path of Figure A. The last two sensors to activate (sensors 6 and 9) are the last sensors on the right-hand side of Rows II and III respectively. Again, since only outer sensors activated, you would probably be right in concluding that the target did not penetrate the inside of the grid. Also, because of the regular stairstep pattern formed by sensors 1, 2, and 3, it can be concluded that the target passed these sensors one right after the other at a relatively constant speed.

It is important also to note that each sensor activated for about the same period of time (2 minutes). This indicates that the target had entered the detection range of each sensor for about the same period of time. Of more importance, this condition implies that the target traveled the same distance away from each sensor. If the activation lengths had differed, this would imply that the target traveled closest to the sensor with the longest activation pattern. We can say this because gain setting, which is important in determining detection ramp, is in the medium range for all the sensors. Keep in mind, however, that other factors can also influence detection range such as the seismic response characteristics of the ground, the environmental/weather factors, and the condition of the equipment.

Review Period - Take a few minutes now and study target 1 and the row patching technique. Start with the X-T plot and retrace the path of target 1 on the grid and try to visualize the relationships that we have just discussed.

b. Example 2 - Target 2

Turn your attention now to target 2. First look at the X-T plot, then the grid. The activations are in which row(s)? _____ Sensor 1 of Row I shows the first activations. The sensor which shows the first activations will usually tell you the closest point in the grid where a target first made contact with the grid by entering or going around the grid. The word usually is used here because in the field another sensor may activate first even though it is further away from the target because of detection range differences. Next, sensor 5 of Row II activated and was followed by sensor 9 of Row III. This indicates that the target moved out of Row II and into Row III.

YOU MUST USE JUDGMENT IN TRACING A TARGETS' PATH AND BE ABLE TO USE CLUES FROM THE LENGTH OF ACTIVATIONS.

It is important to understand the concept of single targets versus multiple targets traveling through the grid. Try the following exercise while still looking at the X-T plot. Imagine that target 1 and target 2 are starting at the same time and progressing through the grid at the same time. In your mind, superimpose target 2 onto target 1 so that the PEN 1 ACTIVATIONS OVERLAP. Now, actually fill in the remaining activations of target 2 with your pencil or pen. Be careful as you fill in the activations to reproduce the same time relationships of target 2.

Now look at the combined activations of both targets carefully. If you had just now seen these activations for the first time would you be able to tell that two targets were involved? Would you have been able

to separate the one long activation pattern on pen 9 into two targets? Remember, several targets can travel through the grid at the same time or close to the same time especially during a battle situation. If an intruder tried this tactic do you think that you would be able to distinguish and report on the separate targets?

Review Period - Take a few minutes and study the combined activation patterns in relation to the paths of these separate targets on the grid.

c. Example 3 - Target 3

Look at target 3 on the X-T plot. Line up your UGS ruler on the X-T plot directly under target 3. Using your UGS ruler to help you with your answer, which pens have activated? _____ It is easy to see that sensors in all three rows have activated. Again it would be safe to assume that the target probably passed through the entire grid.

Notice the differences in the lengths of the various activation patterns on the X-T plot. Generally, you can use this as a guide in giving you an idea as to how close the target came to the various sensors. Compare the lengths of the activations on pens 3 and 8. The activation length on pen 8 is about one minute longer than the one on pen 3. Since the gain setting of all the sensors is the same,

YOU CAN SAFELY CONCLUDE THAT THE TARGET PASSED CLOSER TO THE SENSOR WITH THE LONGEST ACTIVATION PATTERN.

In the example discussed, the target probably passed closer to sensor _____ than it did to sensor 3. Look at the target path in Figure A and check where the target did pass.

Sensors 5 and 6 activated and it would be a reasonable assumption that they are valid activations associated with target 3. Do you think you can conclude the same about the four activations on pen 1? Probably not. Chances are the activations on pen 1 are unrelated to target 3 and probably do not even involve a target. Sensor 1 may be starting to malfunction and if it becomes a "talker" it will run down its power supply.

Look at the X-T plot and answer the following question for the pairs of sensors listed below. The target passed closer to which sensor?

Target 3: Sensor 5 or Sensor 6? _____
Target 3: Sensor 3 or Sensor 5? _____

Now superimpose target 2 which you studied previously onto target 3 so that they start in the same time frame. With your pencil or pen, fill

in the target 2 activations in the same manner that you did previously with target 1. This will take you several minutes to do as before. Now look at the combined activations carefully. If you had just now seen these activations for the first time, would you be able to tell that two targets were involved? Lay your job aid on the X-T plot. Does the job aid help in distinguishing these targets?

Review Period - Take a few minutes and study the combined activation patterns in relation to the paths of these separate targets as shown on the grid.

d. Example 5 - Artillery and Helicopter Activity

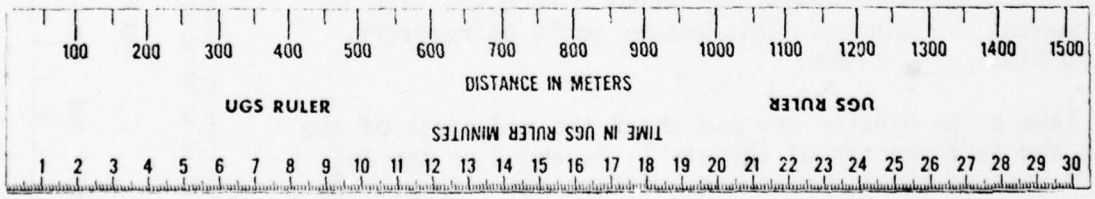
Look in the upper portion of the X-T plot and you will see a typical activation pattern for artillery and helicopter activity. Could you have recognized them if they had not been annotated? An artillery shellburst usually shows as a thin band of one or two activations per sensor with the activations occuring at the same time. Helicopter activity is different in that there are groupings of two or more activations per sensor occuring at the same time. There are more activations because the helicopter is in the area longer and therefore the disturbance created by the helicopter has an effect on the sensors for a longer period of time.

For this exercise circle and annotate on your X-T plot but do not report artillery or helicopter activity as targets. It is important for you to know what it looks like on an X-T plot so you do not report this activity as targets. Study the examples shown.

How Do You Estimate Distance?

Once you have detected a target on the X-T plot, number it, and draw what you think is the path of the target on the grid, you must estimate the distance of that path. This, of course, is step _____ of the seven-step procedure that you learned previously.

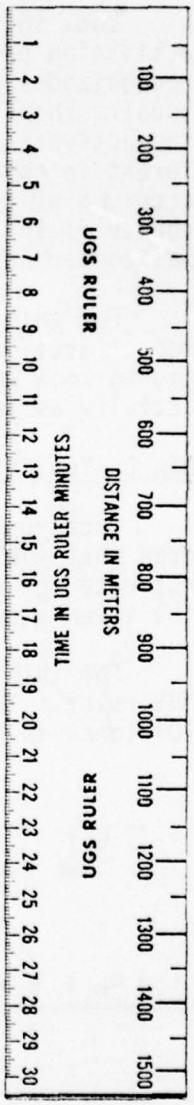
For this task you will find it helpful to use the other side of the UGS ruler. Take your UGS ruler and look for the scale which is labeled "Distance in Meters" as shown below.



To use this scale, place it along a target path that you have drawn on a grid and measure the length of the path to the nearest 50 meters. Remember that the path of an actual target traveling across country will never be a straight line because of turns in the horizontal direction to avoid obstacles and inclines (hills) in the vertical direction.

BECAUSE OF HILLS AND OBSTACLE AVOIDANCE, ALWAYS OVER-ESTIMATE THE DISTANCE IN METERS THAT YOU GET FROM THE UGS RULER.

Using your UGS ruler, measure the target paths drawn in Figure A and check your estimate with the answers already provided. If your answers differ from the given answers by over 100 meters, consult the Training Monitor.



How Do You Determine the Mid-Point Time Difference?

As you learned previously, an estimate of target speed can be made only by knowing the: (1) distance that the target traveled through or around the grid and (2) the amount of time that the target spent in the grid. Step 3 asks for your _____ as to whether you feel you in fact have detected a real target. Step 4 requires you to record the numbers of the first and _____ sensors which activated for the target.

Step 5 requires you to find and mark (on the X-T plot) the mid-points of the activation patterns of the first and last sensors which activated and record the time difference. All considered, the time difference between these two mid-points probably gives you the best estimate of how long the target was in the grid than any other method. Any easy way to estimate this midpoint time difference is to use a scale.

Check the scale on your UGS ruler which is labeled "Time in UGS Ruler Minutes". An example is shown on the right. The scale extends from 0 to 30 minutes and should be adequate for measuring most activation patterns that you will be working with. To use this scale simply measure the distance between the two midpoints as though it were a ruler and you were measuring inches. Read the time to the nearest 1/2 minute. This answer would be recorded in the Step _____ blank.

Take a few minutes now and check the midpoints of the first and last sensors of targets 1, 2, and 3 on the X-T plot. Measure the midpoint time differences with your UGS ruler and see how close you come to the school solutions

provided in Figure A. You may feel that using the UGS ruler for this measurement is not needed because the answers can be sight-read, but remember that these learning targets were intentionally simplified for training purposes and field-collected targets will be more difficult. Also, you will make fewer mistakes if you use the ruler. In the event that your answers differ by over 1/2 minute from the given answers, consult the Training Monitor. If your answers differ by over _____ minutes from the given answers consult the Training Monitor.

How Do You Calculate Speed?

Step 6 requires an estimated average speed concerning the type of target whether vehicle or personnel. In order to save time and avoid arithmetic errors, you should use the Speed Table which you have already been taught to use.

How Do You Determine Target Type?

Step 7 asks that a judgment be made concerning the probable target type. For this particular exercise it will not be necessary to do this. Usually an estimate of target type is based upon an estimated speed greater or less than 150 meters/minute. Since you will be reporting estimated speed, we can score these later using any desired standard.

Monitor Check

Before you begin Part II below, take your materials to the monitor and take a short break.

PART II - PRACTICE TARGETS

Figure C presents an X-T plot of operationally collected targets for you to practice on using the patching technique and principles that you have just learned. After you are finished reading this booklet, study this X-T plot for targets starting at the bottom and working upwards in the order you would see them on a field recorder. For each target that you detect report on it in Figure D.

Figure D presents a blank 9-sensor grid Target Log. Pull it out of your booklet, write your name in the upper right-hand corner and place it in a handy area. Take your other Target Log (Figure A), fold it in half, and place it under your papers where it will not get in the way. As you report on each target, remember to circle all the activations associated with that target by row, number all your circles, and fill in the seven-step procedure in the Figure D Target Log.

USE ALL THREE FUNCTIONS OF YOUR UGS RULER:
SENSOR ROW GROUPS, DISTANCE MEASUREMENT,
AND TIME MEASUREMENT.

As you work through these operationally-collected practice targets, remember that they are not the sterile, ideal examples which you have just worked with. THE PRACTICE TARGETS CONTAIN VARIOUS SOURCES OF BACKGROUND NOISE AND THE EFFECTS OF MALFUNCTIONING SENSORS AND VARIATIONS IN SENSOR DETECTION RANGE DUE TO GAIN SETTING, GROUND/TERRAIN CONDITIONS AND WEATHER. To be able to do a good UGS reporting job, you must learn how to detect and extract target information from X-T plots collected in the field.

Consult the Training Monitor when you feel the need. When you are finished with your practice targets, take your work to the Training Monitor. He will determine whether you need additional practice and/or review.

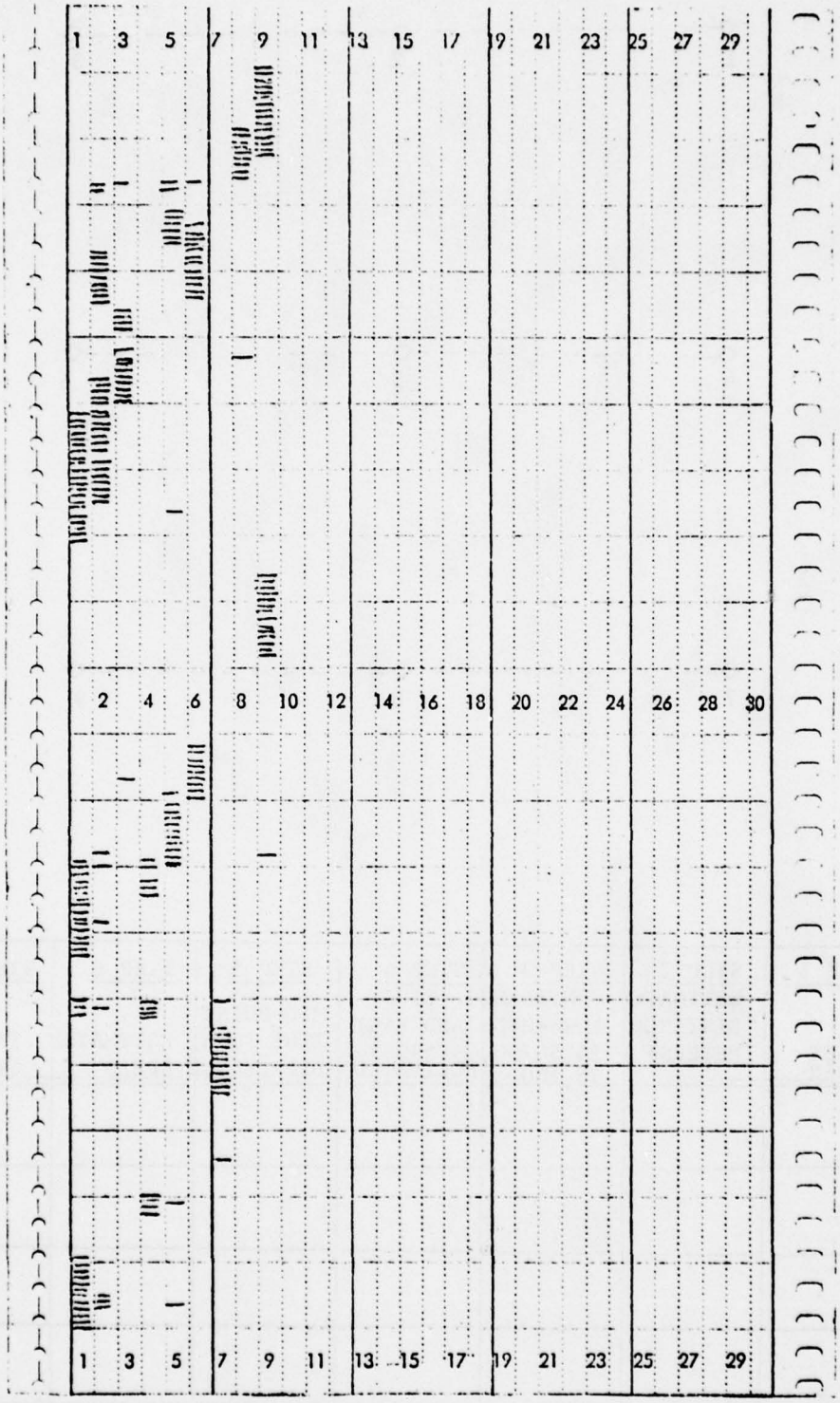
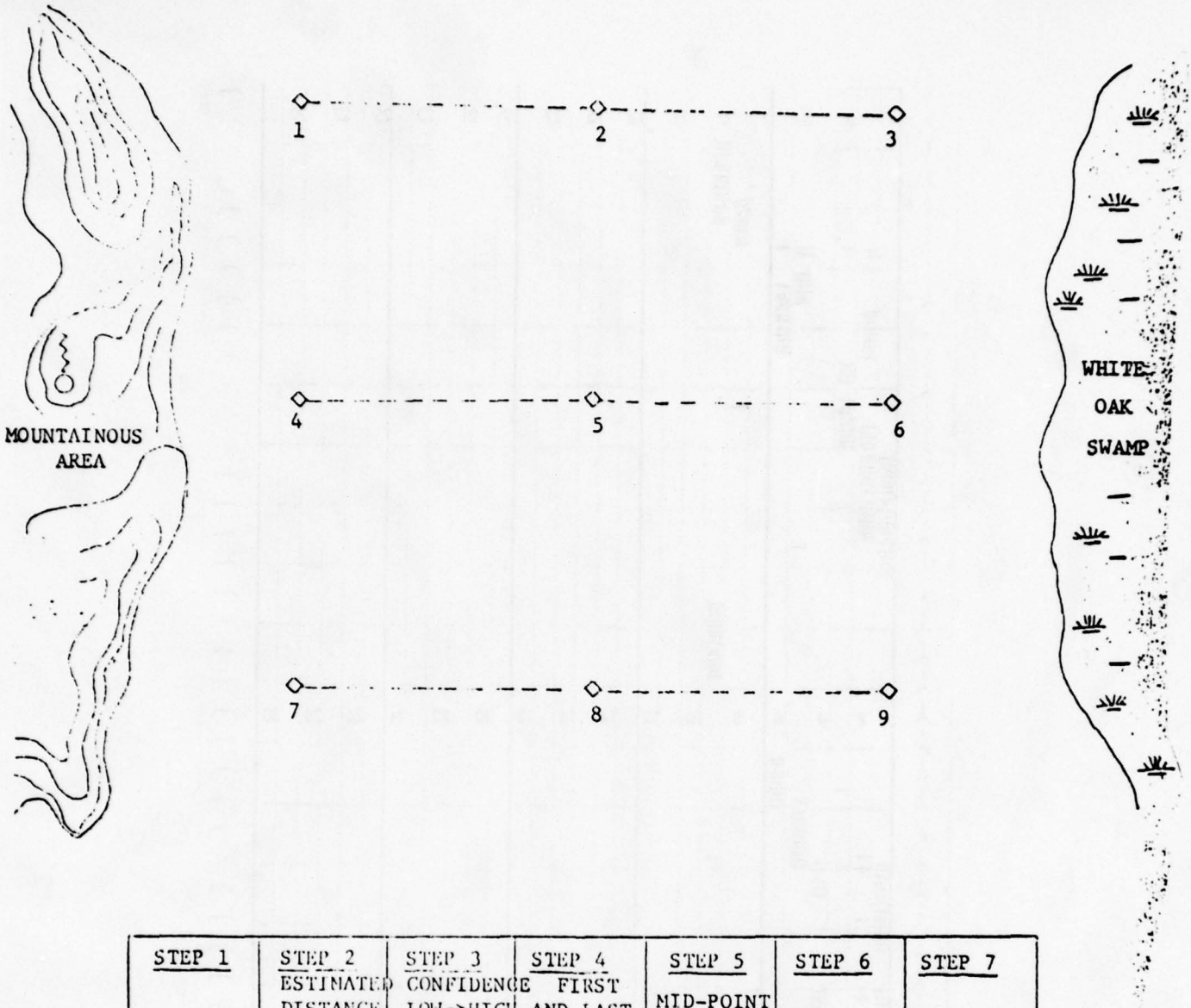


Figure C. X-T plot for row patching using the 9-sensor grid (practice targets).



STEP 1 TARGET NUMBER	STEP 2 ESTIMATED DISTANCE (METERS)	STEP 3 CONFIDENCE LOW→HIGH 25,50/50,75,100	STEP 4 FIRST AND LAST SENSORS ACTIVATED	STEP 5 MID-POINT TIME (min) DIFFERENCE	STEP 6 ESTIMATED SPEED	STEP 7 TARGET TYPE

Figure D. Target log (practice targets).

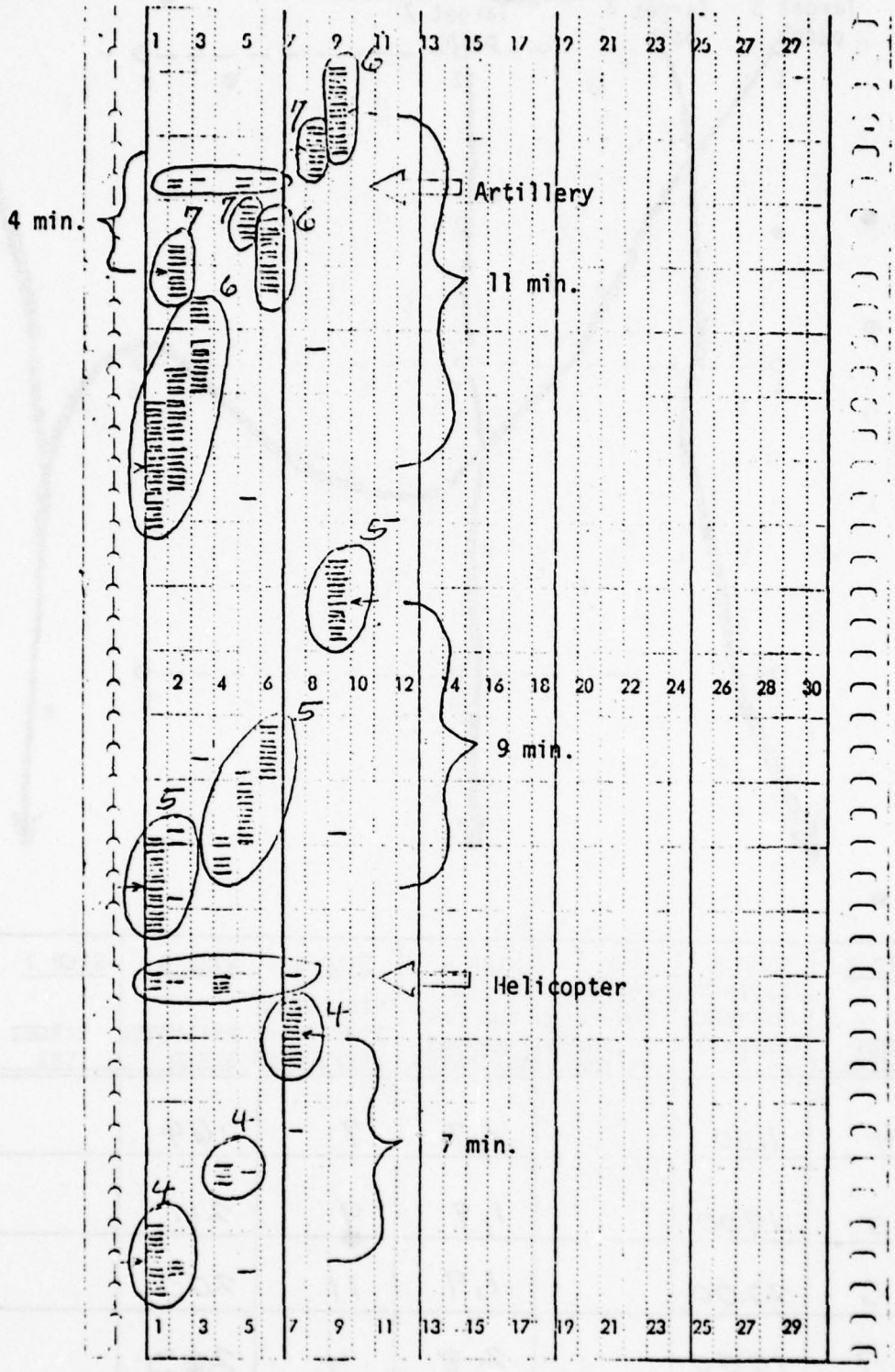
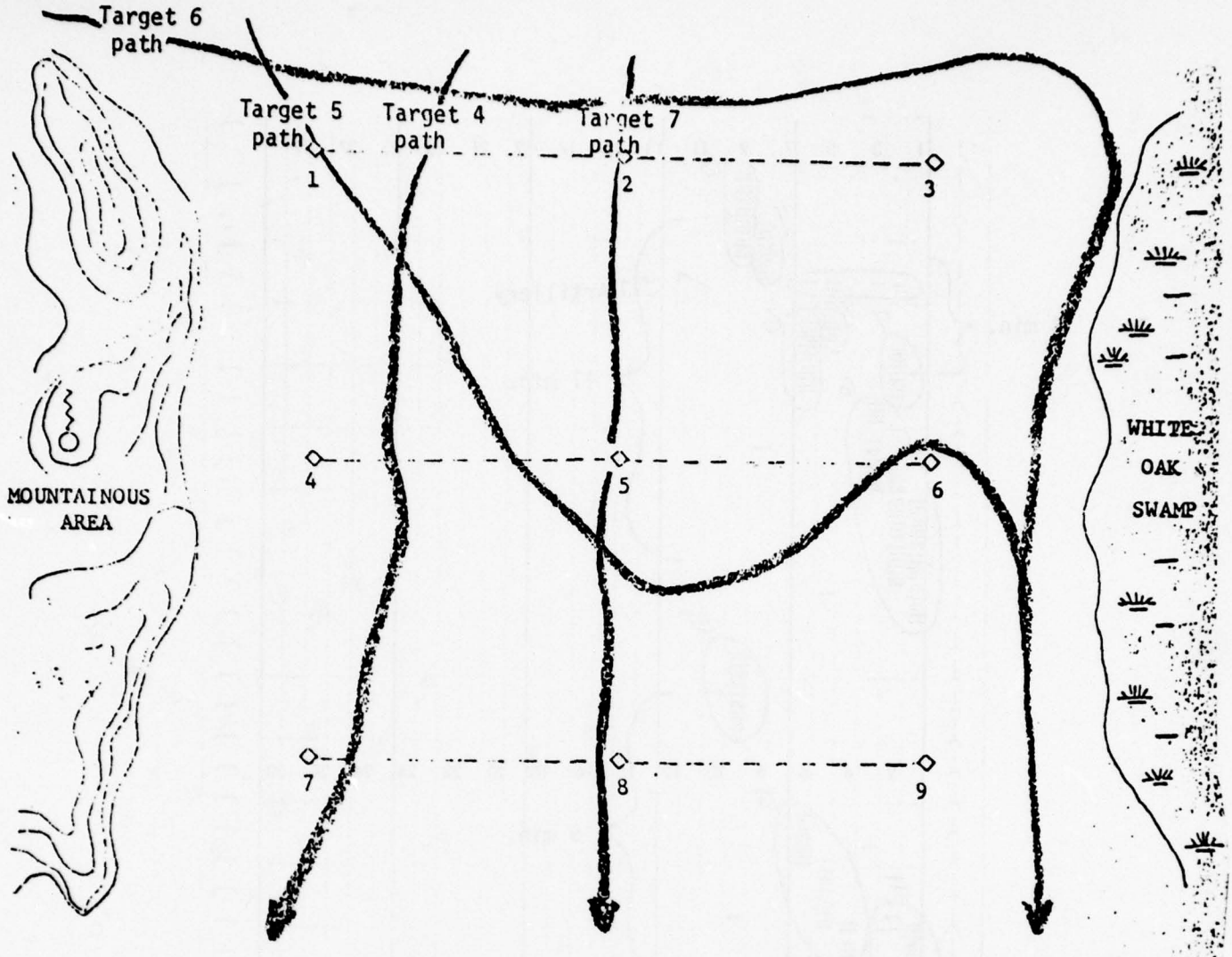


Figure E. X-T plot for row patching using the 9-sensor grid (school solution).



STEP 1 TARGET NUMBER	STEP 2 ESTIMATED DISTANCE (METERS)	STEP 3 CONFIDENCE LOW→HIGH 25,50/50, 75,100	STEP 4 FIRST AND LAST SENSORS ACTIVATED	STEP 5 MID-POINT TIME (min) DIFFERENCE	STEP 6 ESTIMATED SPEED	STEP 7 TARGET TYPE
4	1150		1,7	7	164	
5	1900		1,9	9	211	
6	2200		1,9	11	200	
7	1050		2,8	4	263	

Figure F. Target log (school solution).

APPENDIX B

TARGET QUALITY DISTRIBUTION--NORFOLK SCENARIOS[a]

Field 1			Tape	Field 2			Total
Good[b]	Fair[c]	Poor[d]		Good	Fair	Poor	
5	4	6	A	7	3	2	28
8	4	2	B	7	6	1	28
5	4	3	C	7	5	3	27
	Training		D		Training		23[e]
5	7	4	E	6	4	4	30
23	20	15		27	18	10	113

[a]From Pilette, S., Biggs, B., Edwards, L., & Martinek, H. Optimum patching technique for seismic sensors employed in a grid array. ARI Technical Paper 320, August 1978.

[b]Five targets were detected between 67% and 100% of the time. These are called good or easily detected targets.

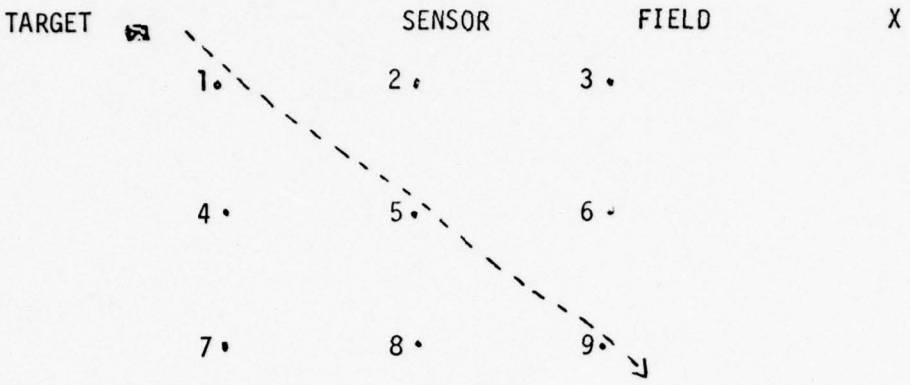
[c]Five targets were detected between 33% and 66% of the time. These are of medium difficulty.

[d]Six targets were detected between 0% and 32% of the time. These are difficult targets.

[e]Extra targets unassessed.

APPENDIX C

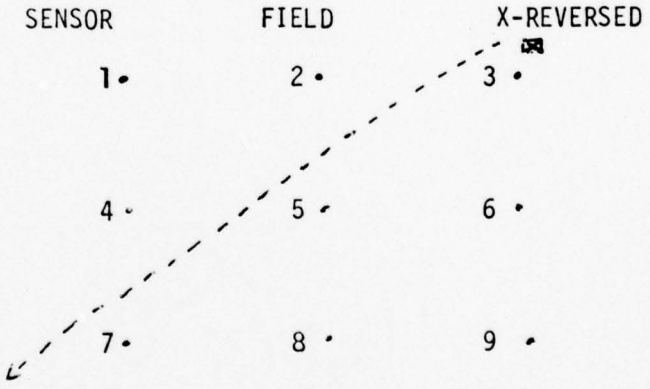
ILLUSTRATION OF SENSOR GRID REVERSAL



In the reversal the following Sensors were transposed:

Sensor 1 with Sensor 3
Sensor 4 with Sensor 6
Sensor 7 with Sensor 9

This reversal produced the grid below:



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APPENDIX D

TARGET QUALITY DISTRIBUTION FOR TARGETS PRESENTED IN THIS STUDY

	Scenario	Good[a]	Fair[b]	Poor[c]
	1	3	1	2
	2	3	3	1
HIGH	3	4	4	0
TARGET	4	3	1	3
ACTIVITY	5	2	3	3
	6	2	4	0
	7	3	3	1
	8	1	1	0
	9	2	1	0
LOW	10	2	0	0
TARGET	11	1	0	1
ACTIVITY	12	2	0	0
	13	1	0	1
	14	1	1	0
		30	22	12

a Targets were detected between 67% and 100% of the time. These are called good or easily detected targets.

b Targets were detected between 33% and 66% of the time. These are of medium difficulty.

c Targets were detected between 0 and 32% of the time. These are difficult targets.

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APPENDIX E

ORIENTATION BRIEFING

Monitor: Paraphrase the following:

I want to welcome everyone here today and thank you for coming. We are glad that you could make it and can participate in the exercises we have planned. We think you will find it worthwhile. You will be participating in a five-day program and we will be spending the next several hours briefing you and giving you an orientation as to what it is all about. Before going any further I want to introduce myself and my associates and find out who you are.

- Introductions -

Our purpose in coming here is to evaluate, with your assistance, several different display/workload conditions using seismic sensors deployed in a grid. We have been asked by the Army Research Institute for the Behavioral and Social Sciences and the Department of the Army to administer this exercise to you. The Army is interested in the development of improved displays of unattended ground sensors to maximize information output and make the job easier for you. Your task in this study will be to act as a sensor operator and interpret various X-T plot presentations. Many of the skills you have acquired in school and on the job will apply to these tasks, however, some of the patching techniques will be new to you and details such as measurement and reporting procedures will differ. In these cases, training and instructions will be provided. If at any time during your work with us you do not understand something or you are not sure of what you are to do -----ASK. You will not be penalized and asking might prevent your having to repeat some of your work. We will be using simulated RO-376 drive mechanisms. If any of the equipment appears to be malfunctioning, inform one of us immediately.

Previous studies of this kind have dealt primarily with sensor strings emplaced along roads, trails, or other infiltration routes. Here, we are applying seismic sensors to an area intrusion problem. In such a situation, we would have sensor fields emplaced over a wide geographical area that an enemy force would utilize should he elect to maneuver his forces cross-country and not along the existing road network. Such a situation could be expected in a mid-intensity conflict in Western Europe. This type of sensor field would be used to help detect and identify different tactical maneuvers such as reconnaissance probes, feints, or major attacks and is referred to as a Gated Array.

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For our experiment, we have taped actual sensor activations from a Gated Array during field exercises using various types of targets. The target activations were collected under simulated battlefield conditions complete with noise activations produced by artillery fire, helicopters, and wind. These tapes will not be played back to you in real time, but in the form of pre-prepared X-T plot scenarios. You will interpret these scenarios and extract information using our procedures and forms. Since we know where and when target activations actually occurred, we can score your reports for accuracy and thereby determine which patching technique can best be used in this particular situation.

Each of you will participate three times this week. Your NCOIC will post the schedule each day. During that time, you will be given training on the row patching technique and multi-display training. During the program you will be given appropriate breaks, lunch, etc. If you cannot be here during the time in which you are scheduled, tell us so we can reschedule you. You must be here for <u>all</u> scheduled times or we cannot use your results.

I would like to emphasize that we are not giving a test to see how good an operator you are. The purpose of this study is to determine what are the effects of different multi-display workload conditions. We are not interested in how good you are as an operator. However, you and your superiors are interested in how good you are. I am sure they will not base the next promotion on how well you do on these practical exercises. <u>Still</u>, these activations <u>are</u> actual activations recorded in the field and your accuracy in interpreting is <u>one</u> indication or example of what you can do. You will be able to compare what you can do to what others did as a group. You will be able to get your score and the group average from your commanding officer. He will be able to objectively assess you against the others on this one sample of one of your duties. However, there are no standards of performance -- even if you do worse than everyone you still could be a competent operator.

All we ask is that you interpret the X-T plots to the best of your ability and try to make sense out of what sometimes might appear to you to be rather difficult. Let me stress that we have tried to make these records as realistic as we could.

You are important because you as a group represent the hundreds of specialists that have graduated and will graduate from the UGS school for a long time to come. Army deployment plans for UGS equipment and personnel will be partly influenced based upon what <u>you</u> can do.

<u>Monitor</u>: Begin the briefing on grid deployment patterns.

APPENDIX F

INTRODUCTION TO THE GRID DEPLOYMENT PATTERN
(LECTURE/DISCUSSION)

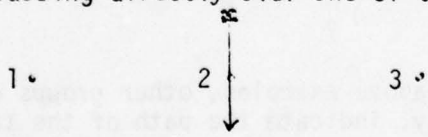
The Grid array consists of unattended ground sensors (UGS) deployed in a matrix within a designated field area as opposed to the string pattern in which UGS are deployed in sequential alignment along a roadway. The grid array can be used for area intrusion surveillance problems encompassing entire border areas or smaller gate (gap) areas where coverage by radar or other means is limited or not feasible. It is designed to maximize the probability of detecting and acquiring enemy forces intruding in any portion or in any direction within a covered geographical area. The UGS in the grid array are deployed in a systematic way with pre-planned distances between the sensors so that information extraction is enhanced.

For this exercise we are utilizing a sensor grid, consisting of 9 sensors, each sensor is 500 meters apart. X-T plot readouts of various target runs through this sensor grid will be presented to you. Your task will be to detect these targets, track their path through the sensor grid, and provide further information about them. You have already received some information concerning this task. At this time we would like to provide you with further information which should aid you in monitoring sensors in the sensor grid.

After you have detected what you believe is a target, your next objective is to chart or trace its path across the sensor grid. In the past, when you have worked with sensor strings, targets coming down a road will generally activate all the sensors in order. However, in a grid formation, the targets may come from any direction and take any course across the grid. They will also come closer to some sensors than they will to other sensors. This presents more of an interpretation problem to the monitor.

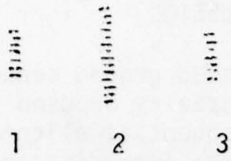
We have prepared some examples of targets entering the sensor grid from different angles and taking different paths through the grid. We also have copies of the sensor activations caused by these targets.

Example 1 - Here is a target entering a grid, and crossing the first line of sensors, passing directly over one of them.

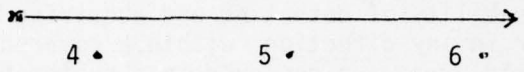


Activations would first appear on the middle sensor. As the target proceeds the sensors to the right and left would activate for a shorter

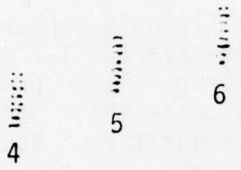
period of time. The sensors to the right and left would cease activating before the middle sensor thus the activations would appear as below:



Example 2 - A target traveling in parallel with a line of sensors would

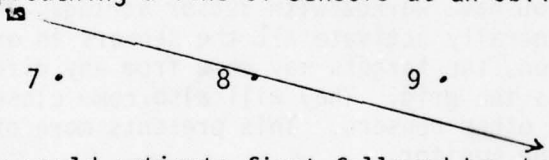


appear like this on the X-T plot.

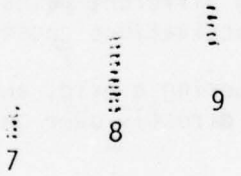


This would be very similar to the activation of a sensor string with a stair-step pattern. All sensors would activate for approximately the same length of time.

Example 3 - Shows a target approaching a line of sensors at an oblique angle.



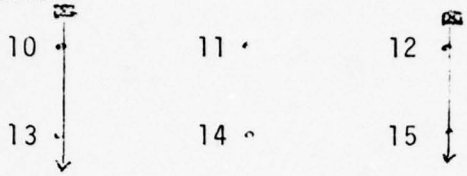
Here the left hand sensor would activate first followed by the middle sensor and the right-hand sensor, however, the middle sensor would be activated for a longer time because the target would come closest to it.



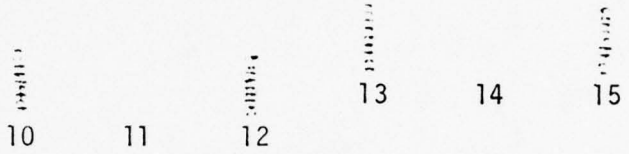
In all three of the above examples, other groups of sensors in the grid would, in the same way, indicate the path of the target as it traveled the grid. A good general rule to remember when monitoring a sensor grid is to look at the overall pattern of the sensors being activated, and then make a determination from this overall pattern, where the target is traveling.

At times, there may be more than one target present in the sensor field. Monitors should be able to detect this again by studying the overall pattern of activations

Example:



In this example, with sensors activating on the left and right but not in the middle, it must be assumed that two targets are present. In these situations it is important to take note of sensors that are not activating as well as sensors that are activating.



APPENDIX G

TEST PROCEDURE TRAINING

Our purpose in coming here this week is to evaluate several display and target conditions for seismic sensors patched to an RO376 readout device. We want to determine how different display and target activity conditions affect your ability to detect and report on targets. You are all familiar with the idea of deploying sensors in a string configuration along a road. Now you will be working with sensors deployed in a grid configuration and in a field such as that shown in the top half of Figure 1.

Pull Figure 1 and Figure 2 out of this booklet and lay them on your desk where you can see both of them clearly. As you can see, Figure 1 shows 9 sensors deployed in a grid which is 1000 meters on a side. Compare this with Figure 2 which shows 24 sensors also deployed in a grid 1000 meters on a side. The sensor identification numbers are shown in both figures. In an operational situation, grids this size could be a small section out of a long sensor network or they could be placed between natural barriers. For our purposes, assume that each grid is located in a flat partially wooded field between rugged terrain on the left and marshy terrain on the right.

The expected direction of enemy approach is from top to bottom. As you can see, target 1 in both grids has come from the expected direction and has passed through the center of the sensor field. In the case of the 9-sensor grid, the target has passed over sensors 11, 15, and 14. In the case of the 24-sensor grid, at least three more sensors are involved. As you can see by inspection, the target has passed over sensor 11, between sensors 9 and 23, and then over sensors 15, 13, and 14. These additional sensors may help when reporting on a target from an X-T plot.

The bottom half of Figures 1 and 2 shows blank spaces and a seven step procedure which you will use to report on targets.

> YOUR JOB DURING THIS EXERCISE WILL BE TO FIND TARGETS ON X-T PAPER AND FOR EACH ONE THAT YOU FIND, FILL IN THE BLANKS FOR THE SEVEN STEPS.

You will be working with X-T chart paper and targets similar to that shown in Figure 3 (second to the last page). Study Figure 3. Notice the pen/ID chart at the side showing that the X-T pen numbers correspond to the same sensor grid numbers.

At this time we will define what we mean by the word "target". A target is any vehicle or personnel activity in the field which is distinguishable from other personnel or vehicle activity. For example, three

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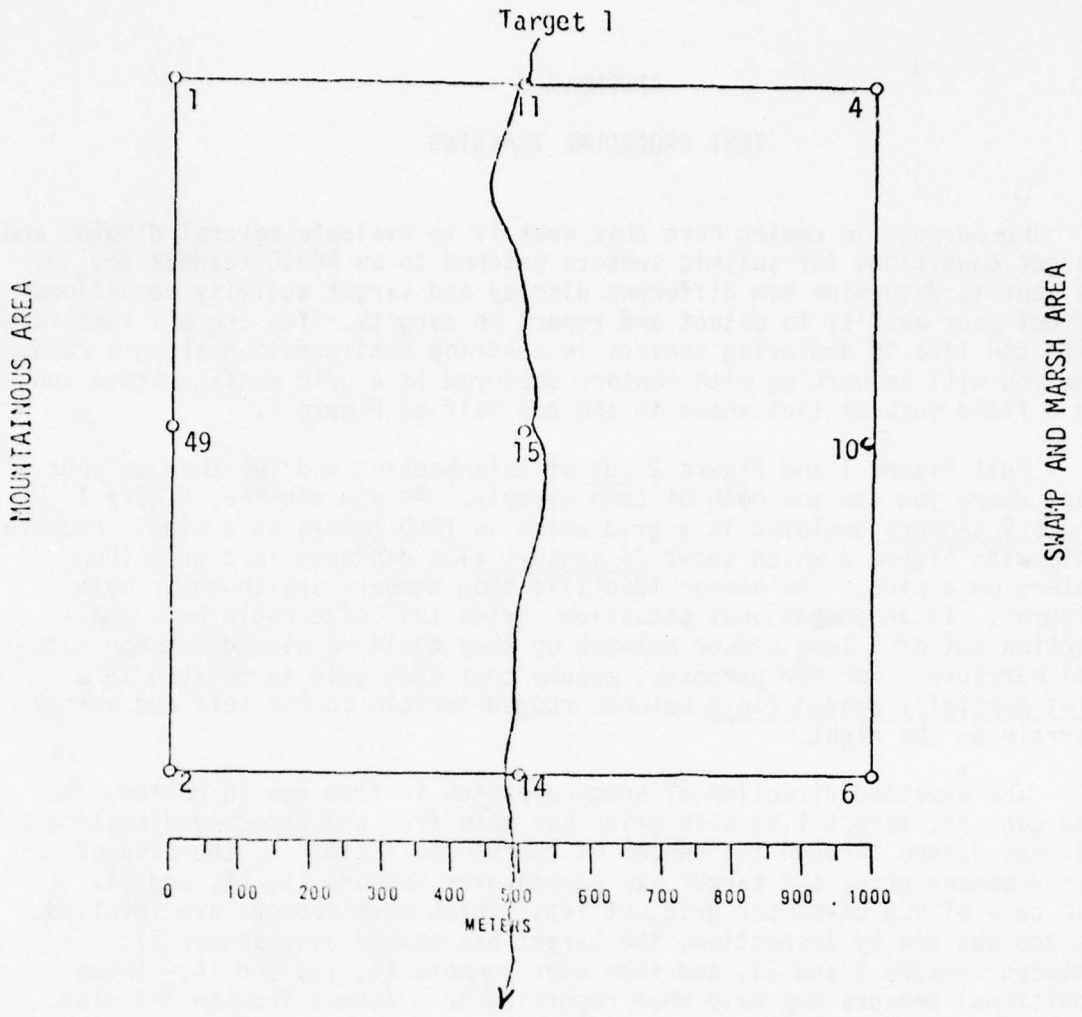
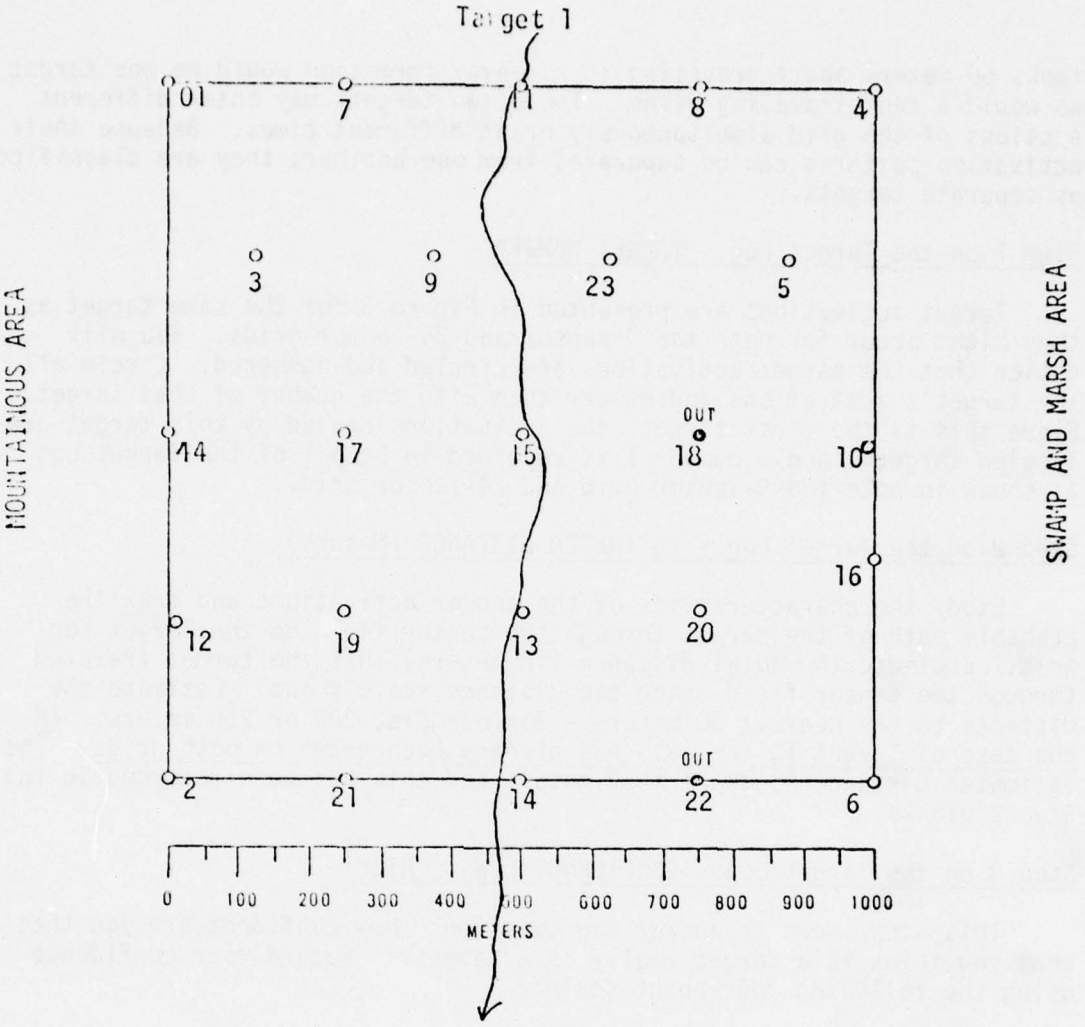


STEP 1 TARGET NUMBER	STEP 2 ESTIMATED DISTANCE (meters)	STEP 3 CONFIDENCE LOW → HIGH 25,50/50, 75,100	STEP 4 FIRST AND LAST SENSORS ACTIVATED	STEP 5 MID-POINT TIME(min) DIFFERENCE	STEP 6 ESTIMATED SPEED	STEP 7 TARGET TYPE
1	1050	100%	PENS 11,14	8	$\frac{1050}{8} = 131$	

Figure 1. 9-sensor target log.



STEP 1 TARGET NUMBER	STEP 2 ESTIMATED DISTANCE (meters)	STEP 3 CONFIDENCE LOW → HIGH 25,50/50, 75,100	STEP 4 FIRST AND LAST SENSORS ACTIVATED	STEP 5 MID-POINT TIME(min) DIFFERENCE	STEP 6 ESTIMATED SPEED	STEP 7 TARGET TYPE
1	1050	100%	PENS 11,14	8	$\frac{1050}{8} = 131$	

Figure 2. 24-sensor target log.

tanks 50 meters apart traveling in a convoy formation would be one target as would a tank traveling alone. These two targets may enter different sections of the grid simultaneously or at different times. Because their activation patterns can be separated from one another, they are classified as separate targets.

Step 1 on the Target Log - TARGET NUMBER

Target activations are presented in Figure 3 for the same target as they might occur for both the 9-sensor and 24-sensor grids. You will notice that the target activations are circled and numbered. Circle all the target's activations and number them with the number of that target. Since this is the first target, the activations caused by this target are labeled target 1 and a number 1 is recorded in Step 1 of the Target Log as shown in both the 9-sensor grid and 24-sensor grid.

Step 2 on the Target Log - ESTIMATED DISTANCE (Meters)

Study the characteristics of the sensor activations and draw the probable path of the target through the sensor field on the Target Log grid. Estimate the total distance (in meters) that the target traveled through the sensor field using the distance scale shown. Estimate the distance to the nearest 50 meters - for example, 200 or 250 meters. In the case of Target 1, the path has already been drawn on both grids. The estimated distance is about 1050 meters and this has been recorded in the Step 2 blanks.

Step 3 on the Target Log - CONFIDENCE LOW HIGH

This step seeks to answer the question, "How confident are you that what you think is a target really is a target?" Record your confidence using the following four-point scale:

100% - This means you are positive or certain.

75% - This means you are highly confident, but not positive.

50/50% - This means that you think it probably is a target, but you are uncertain - it may not be a target.

25% - This means that you have only a suspicion, but it should be recorded and checked out. You have low confidence that this is a target.

A 100% confidence has already been placed in this column on the Target Log.

Step 4 on the Target Log - FIRST AND LAST SENSORS ACTIVATED

Record the sensor number of the first sensor which activated when the target entered the grid and the last sensor which activated when the target left the grid. As shown for both the 9-sensor and 24-sensor grids, the first sensor is 11 and the last is 14 which is the same as pens 11 and 14 on the X-T plot. Check this yourself by looking at the pen/ID chart on the right-hand side of Figure 3. This information is important because it will be used for the next steps.

Step 5 on the Target Log - MID-POINT TIME (Min) DIFFERENCE

On the X-T plot, find the mid-point of the activation patterns for the first and last sensors. Now determine the time difference between the two mid-points. This is done directly off the X-T chart paper as shown in Figure 3 for both the 9-sensor and 24-sensor grids. Remember, there are 2 minutes between lines (rows) on the X-T chart paper. Estimate this time to the nearest half minute, for example 3 or 3.5 minutes. For Target 1 the mid-point time difference is _____ minutes. Check your answer with the appropriate Target Logs for the two grid sizes. If you missed it, reread this section and/or see the Training Monitor.

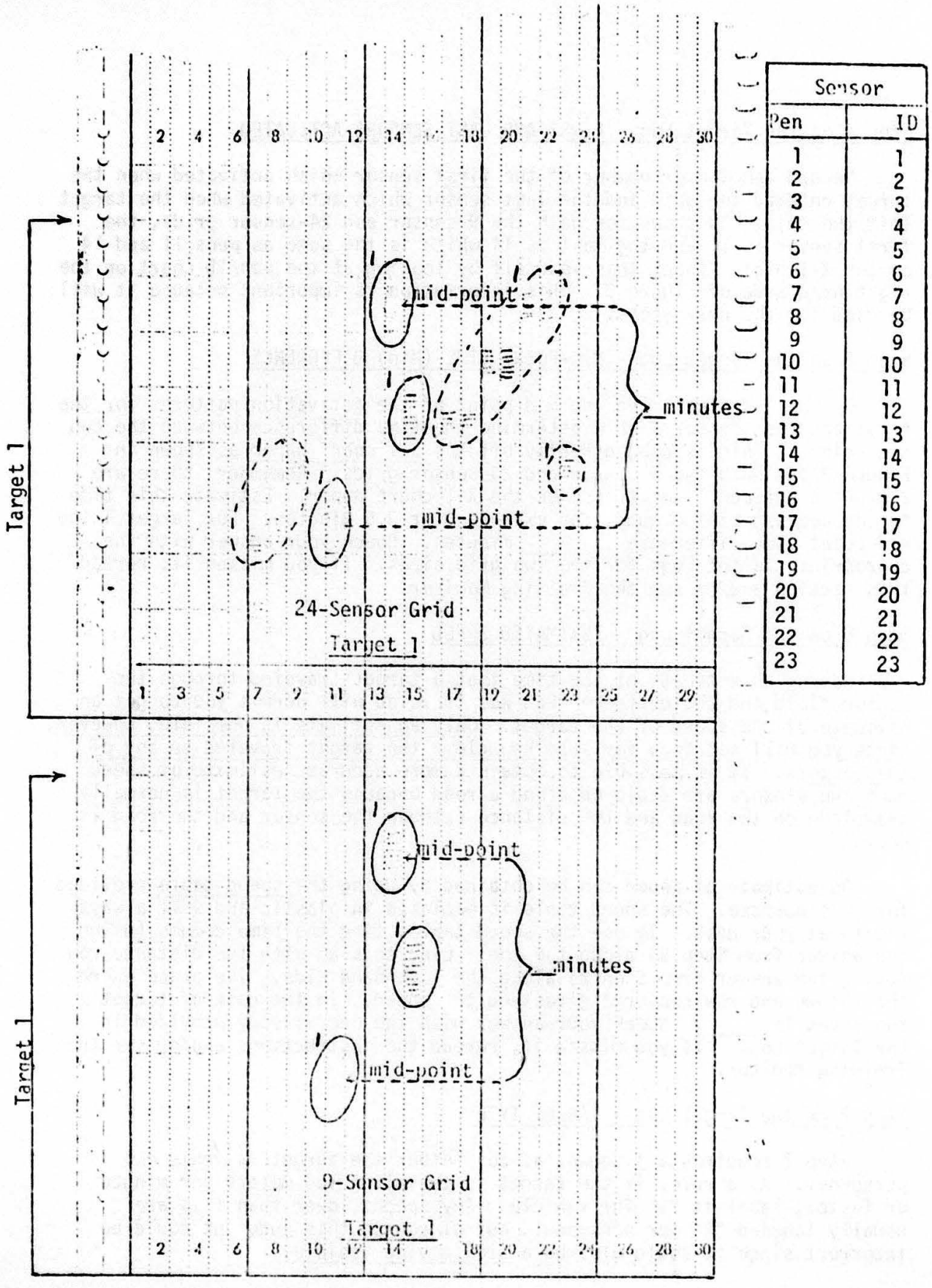
Step 6 on the Target Log - ESTIMATED SPEED

Having an estimate of the time that a target traveled through the sensor field and the distance that was traveled will permit you to get an estimate of the speed of the target. Only an estimate is possible, however, since you will not know for sure how close the target traveled to any of the sensors. It is possible to obtain a more accurate estimate of speed when the sensors are deployed along a road because the target is normally traveling on the road and the distance between the sensor and the road is known.

An estimate of speed can be obtained by using the speed table provided for this purpose. The speed table is enclosed in plastic and will always remain at your desk. To use the speed table, find the time column (using the answer from Step 5) along the top. Line this up with the distance row (using the answer from Step 2) along the left-hand side. The place where the column and row converge gives you the speed. In the case of target 1 the speed is _____. Check your answer with the one already provided in the Target Logs. If you missed it, reread the instructions and/or see the Training Monitor.

Step 7 on the Target Log - TARGET TYPE

Step 7 requires a judgment as to whether the target is vehicle or personnel. As a rule, if the target is traveling 150 meters per minute or faster, label it "V" for vehicle. Any speeds lower than this are usually labeled "P" for personnel, but of course this judgment could be incorrect since it could also be a slow moving vehicle.



Pen	ID
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10
11	11
12	12
13	13
14	14
15	15
16	16
17	17
18	18
19	19
20	20
21	21
22	22
23	23

Figure 3. 9- and 24-sensor grids.

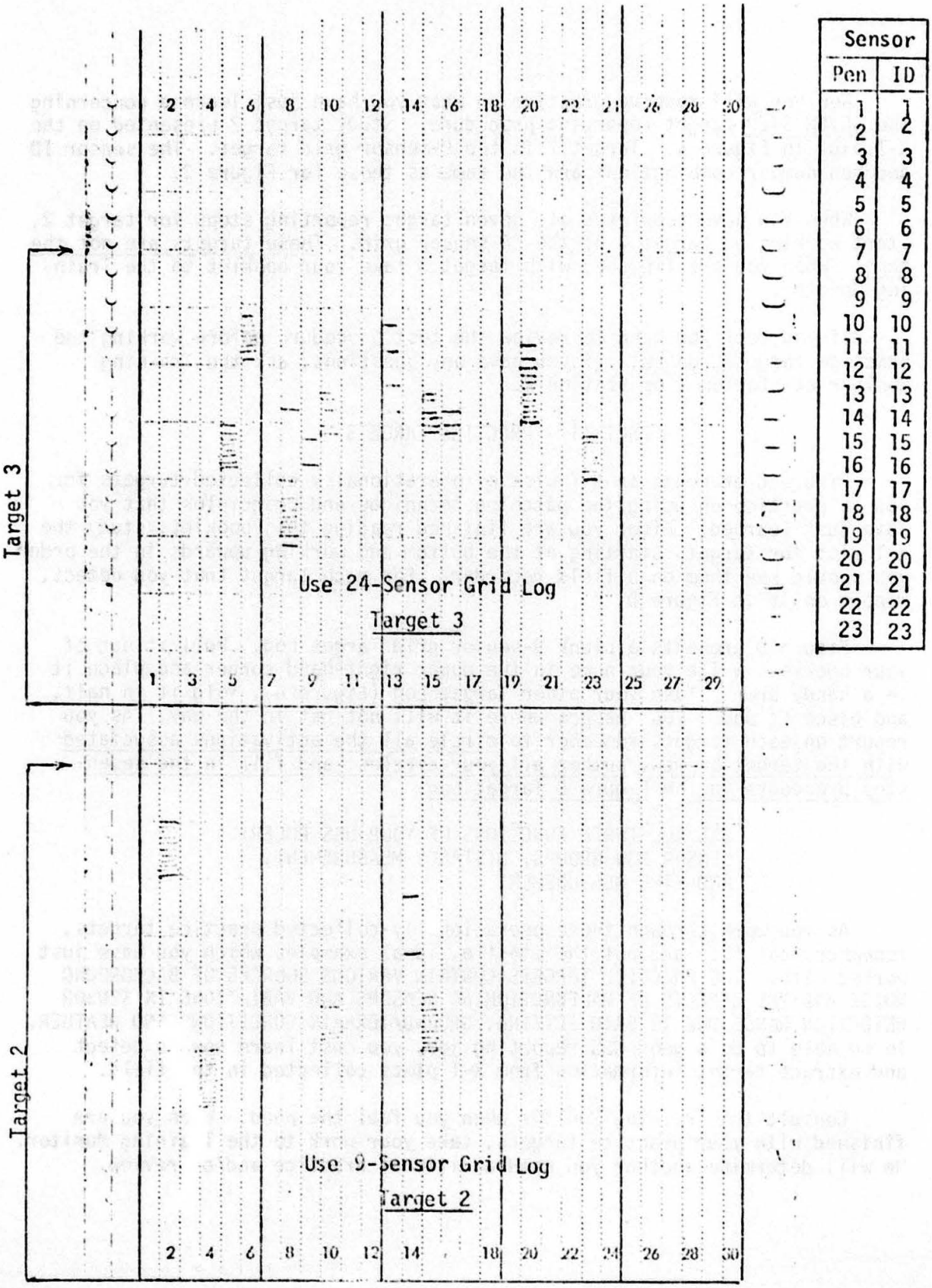


Figure 4. 9- and 24-sensor grid logs.

Now you will receive practice on what you have just learned concerning the SEVEN STEP target reporting procedure. Study target 2 presented on the X-T plot in Figure 4. Target 2 is the 9-sensor grid target. The sensor ID and pen number combinations are the same as those for Figure 3.

When you have completed all seven target reporting steps for target 2, start working on target 3 of the 24-sensor grid. These targets are not the same! When you are finished with target 3 take your booklet to the Training Monitor.

If you feel you need to review the test procedure before working the practice targets, do so! If you have any questions, ask the Training Monitor at Station 1 or Station 2.

PART II - PRACTICE TARGETS

Figure C presents an X-T plot of operationally collected targets for you to practice on using the patching technique and principles that you have just learned. After you are finished reading this booklet, study the X-T plot for targets starting at the bottom and working upwards in the order you should see them on a field recorder. For each target that you detect, report on it in Figure D.

Figure D presents a blank 9-sensor grid Target Log. Pull it out of your booklet, write your name in the upper right-hand corner and place it in a handy area. Take your other Target Log (Figure A), fold it in half, and place it under your papers where it will not get in the way. As you report on each target, remember to circle all the activations associated with the target by row, number all your circles, and fill in the seven-step procedure in the Figure D Target Log.

USE ALL THREE FUNCTIONS OF YOUR UGS RULER:
SENSOR ROW GROUPS, DISTANCE MEASUREMENT,
AND TIME MEASUREMENT.

As you work through these operationally-collected practice targets, remember that they are not the sterile, ideal examples which you have just worked with. THE PRACTICE TARGETS CONTAIN VARIOUS SOURCES OF BACKGROUND NOISE AND THE EFFECTS OF MALFUNCTIONING SENSORS AND VARIATIONS IN SENSOR DETECTION RANGE DUE TO GAIN SETTING, GROUND/TERRAIN CONDITIONS AND WEATHER. To be able to do a good UGS reporting job, you must learn how to detect and extract target information from X-T plots collected in the field.

Consult the Training Monitor when you feel the need. When you are finished with your practice targets, take your work to the Training Monitor. He will determine whether you need additional practice and/or review.

There is one additional point which must be made because it is an important part of your response. Each time that you draw the path of a target through the grid, at the end of the target path draw an arrow showing the direction that you think the target will continue to travel. Assume that your target directions and speed information will be used by your CO for fire control purposes.

APPENDIX H

MULTI-DISPLAY PROCEDURE TRAINING (LECTURE/DISCUSSION)

Monitor: Paraphrase the following:

To familiarize you with the procedures needed to monitor one 30-pen, two 30-pen, and four 30-pen displays simultaneously using the seven-step reporting procedure. Each person will have an opportunity to interpret targets at each display condition. Each 30-pen display contains three 9-sensor grids. The following diagram clarifies the grid arrangement.

Monitor: Draw this picture on the blackboard and paraphrase the following.

	Display		
Grid	1	2	3
Pens	1-9	11-19	21-29

As you can see in the diagram there are three 9-sensor grids in each display. For each display:

Grid 1 is composed of sensors 1-9 and uses the green Target Log. (verify this)

Grid 2 is composed of sensors 11-19 and uses the yellow Target Log. (verify this)

Grid 3 is composed of sensors 21-29 and uses the salmon Target Log. (verify this)

Take the target logs located on your desk and study them in relation to the three grids. Notice how the grids are geographically related to each other.

When you detect a target you will report on it using the seven-step procedure that you have already learned. However, there is one important exception.

For each target that you report, you must include a display letter (A, B, C, or D). At this time, check to see which display or displays you are working with. The purpose in you doing this is so that we know which display the target falls in. For each target that you report, therefore, always include the display letter in which the target is located.

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The place to report the display letter is with the target number in Step 1. Suppose the fifth target that you have detected is located in Display A, Grid 2. In Step 1 under the Target Number heading on the blue Target Log, you would write A-5. Suppose that the tenth target that you detect falls in Display B, Grid 1. For this example, in Step 1 under the Target Number heading of the (green/yellow/salmon) Target Log you would write _____.

Monitor: Go through several more examples to be sure everyone understands. Paraphrase the following:

Find your job aid (UGS ruler). Turn to the side that has the 9-pen scale. You will be able to use this ruler effectively if you desire. The ruler, as you have already learned, is divided into three sections. Each section is a different color and represents a different row of sensors. This ruler can be used for each of the three grids that you will be working with in each display as shown in the diagram.

1	2	3	4	5	6	7	8	9	Grid 1
11	12	13	14	15	16	17	18	19	Grid 2
21	22	23	24	25	26	27	28	29	Grid 3

Of course, when you are working with Grid 1, you will be working with sensor 1-9. When you are working with Grid 2, simply add 10 to each pen/sensor number and use the ruler as you have learned. When you are working with Grid 3 simply add 20 to each pen/sensor number and use the ruler as you have learned.

Monitor: Be sure that practice targets are in position on all of the displays for a practice session. Paraphrase the following:

You will now be given practice scenarios to work with. Detect and report on two targets using the procedure that you have learned. After you have completed reporting on these practice targets, take your target log sheet or sheets to the training monitor. He will check your work and determine if you need more practice targets.

After you have completed the practice targets you will be rotated to a different display condition and you will report on two more targets. Since under some display conditions you will be monitoring more grids and sensors there is a good chance that you will be detecting and reporting on more targets. As you work through the practice targets, think about how you would successfully handle heavy target activity situations. In

these situations, your time would be at a premium and you must know your procedures well. For example, if you have detected three targets simultaneously you would want to share your time evenly with all three rather than with just one of them. Time/task sharing is therefore important.

Monitor: Begin the practice phase to complete the first cycle of display training and practices. Rotate the students and complete cycle 2 and 3 in the same manner.

APPENDIX I

TARGET LOGS

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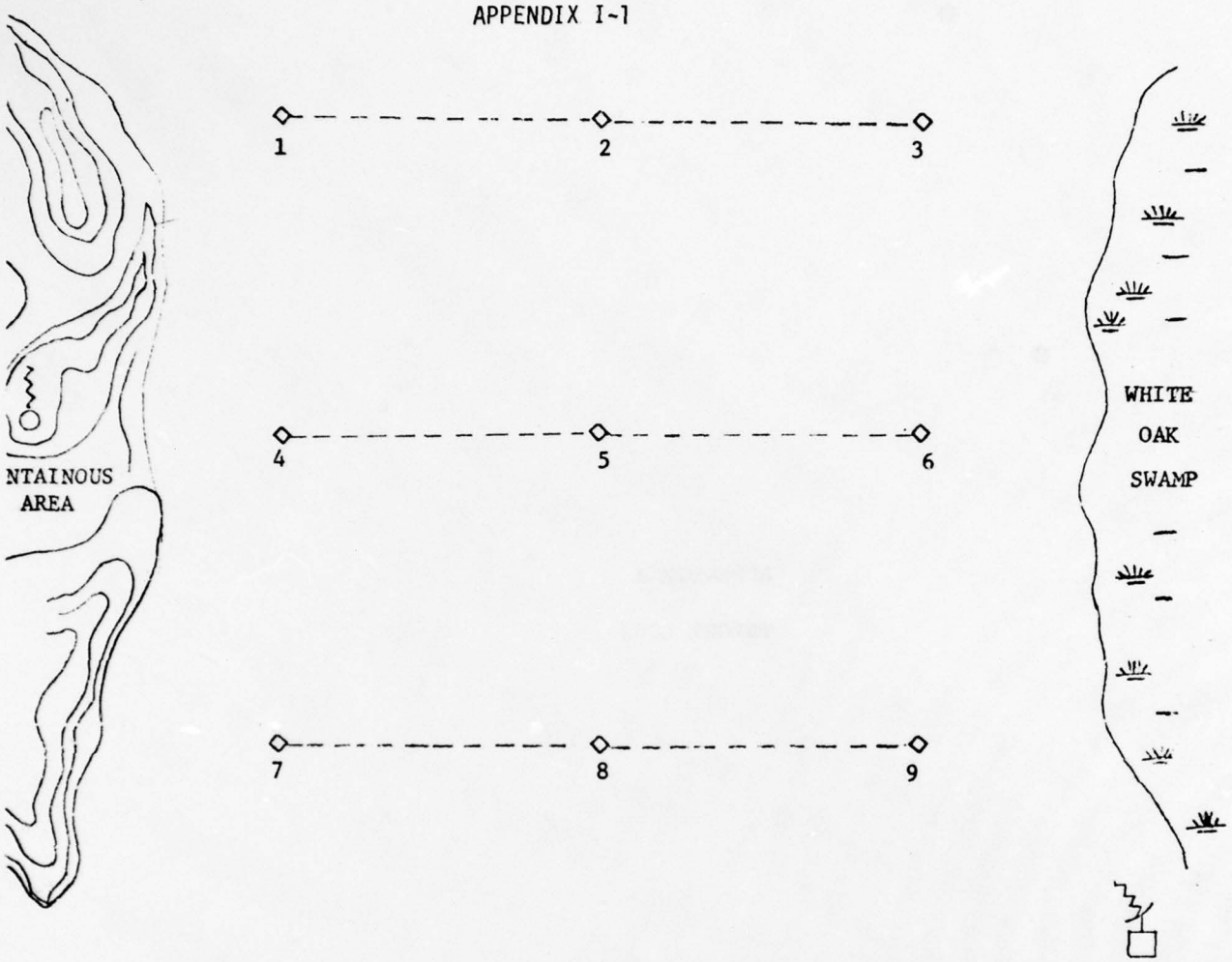
GRID I
Target Log

OPERATOR _____

APPENDIX I-1

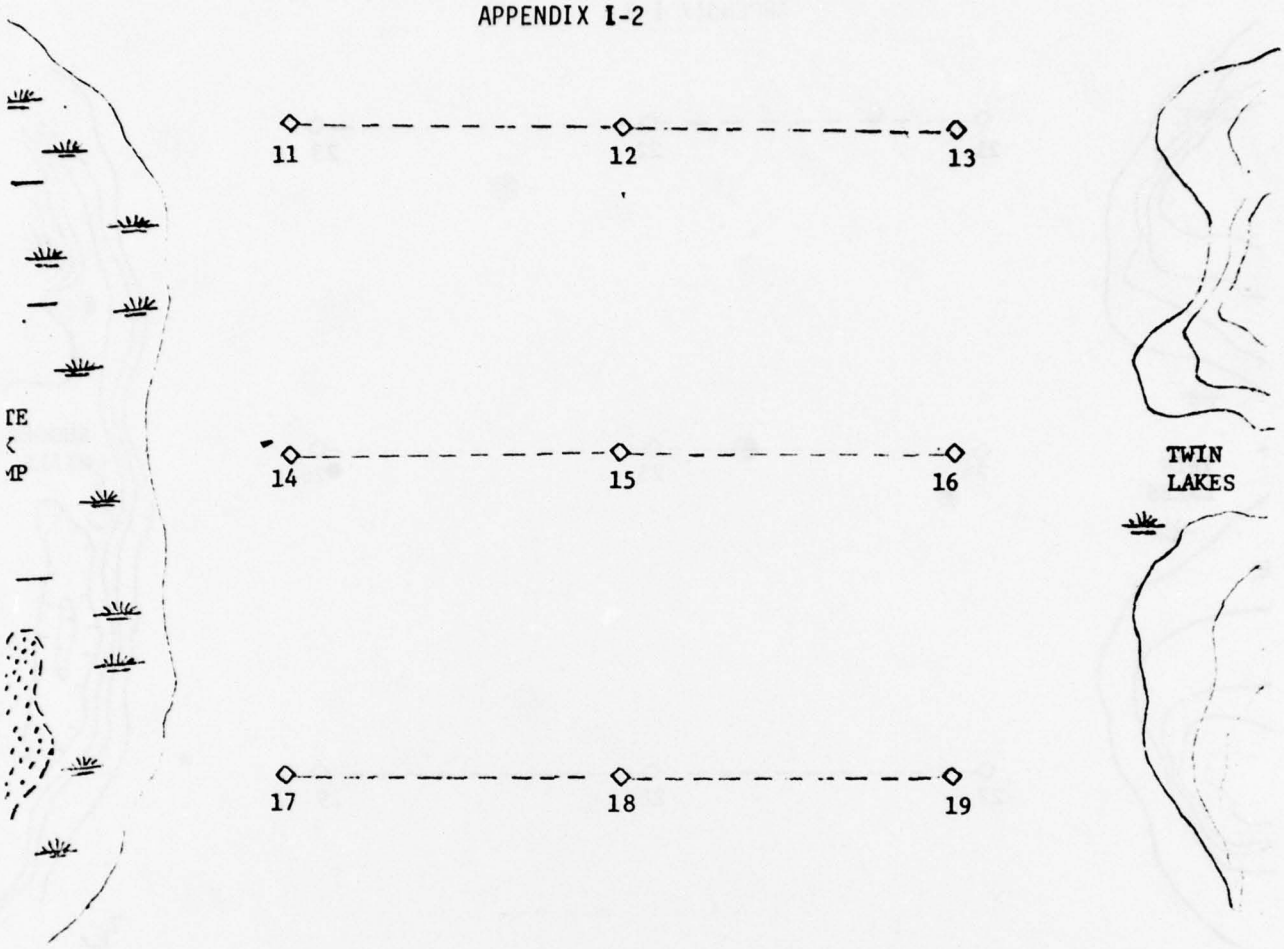


STEP 1 DISPLAY LETTER/ TARGET NUMBER	STEP 2 ESTIMATED DISTANCE (METERS)	STEP 3 CONFIDENCE LOW→HIGH 25,50/50, 75,100	STEP 4 FIRST AND LAST SENSORS ACTIVATED	STEP 5 MID-POINT TIME (min) DIFFERENCE	STEP 6 ESTIMATED SPEED	STEP 7 TARGET TYPE

GRID II
Target Log

OPERATOR_____

APPENDIX I-2

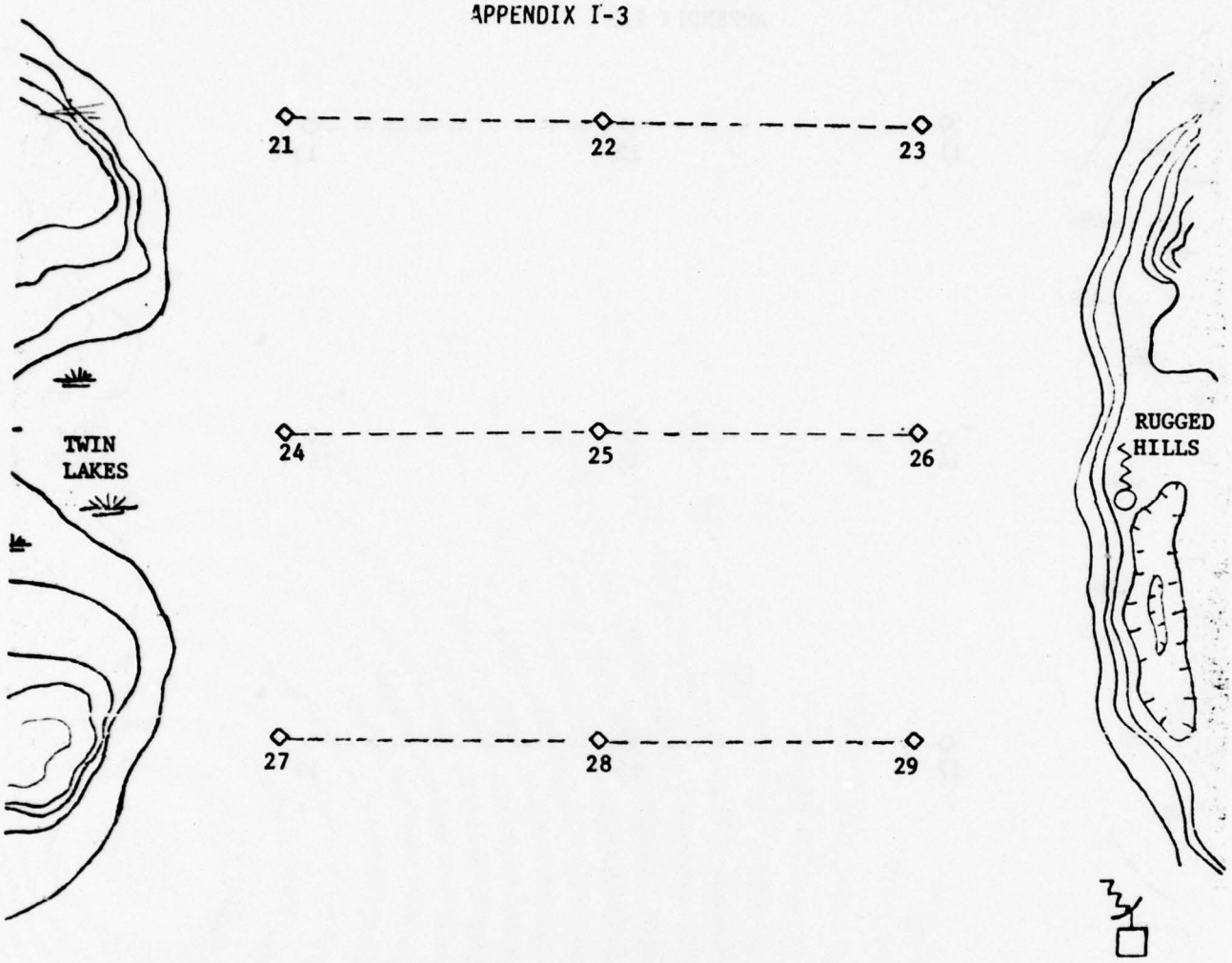


STEP 1 DISPLAY LETTER/ TARGET NUMBER	STEP 2 ESTIMATED DISTANCE (METERS)	STEP 3 CONFIDENCE LOW→HIGH 25,50/50, 75,100	STEP 4 FIRST AND LAST SENSORS ACTIVATED	STEP 5 MID-POINT TIME (min) DIFFERENCE	STEP 6 ESTIMATED SPEED	STEP 7 TARGET TYPE

GRID III
Target Log

OPERATOR_____

APPENDIX I-3



STEP 1 DISPLAY LETTER/ TARGET NUMBER	STEP 2 ESTIMATED DISTANCE (METERS)	STEP 3 CONFIDENCE LOW→HIGH 25,50/50, 75,100	STEP 4 FIRST AND LAST SENSORS ACTIVATED	STEP 5 MID-POINT TIME (min) DIFFERENCE	STEP 6 ESTIMATED SPEED	STEP 7 TARGET TYPE

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1 HQDA (DAPE-MPO-C)
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